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CAMP SANITATION.*

BY

W. P. MASON, M.D., LL.D.,

Professor of Chemistry, Rensselaer Polytechnic Institute, Troy, N. Y.

In these days of military activity, with soldiers widely scattered throughout the land, a camp is naturally conceived of as having to do with war, and relatively little thought is given to those gatherings of men who are occupied with the activities of peace.

Certain well-defined differences must be recognized between labor camps and those of soldiers, the most notable of which is the existence of military authority in the one and its entire absence in the other. When provision is being made for a group of men accustomed to obey orders, who are equipped in all particulars with uniformity, who are subject to military authority, and who are protected thereby from the dangers of irregular and vicious living, the camp problem assumes a simplicity of solution quite in contrast with that presented when arrangements have to be made for a collection of persons gathered from many sources, frequently of many nationalities and different languages, often very ignorant, and all imbued with a spirit of independence that causes them to resent what they believe to be an interference with their personal liberty.

* Presented at the Annual Meeting of the Institute, held Wednesday, January 16, 1918.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

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In perhaps no other way is their resentment so likely to be aroused as by attempts to control their movements during off-hours. Any approach toward making prisoners of camp employees is bound to produce resistance on the part of a majority of them, even though the more intelligent few may be persuaded of the advantage accruing from stopping a too free passage to and from the general enclosure. A man-proof fence with single gateway has its advantages, even though no physical interference be attempted with an inmate passing the guard.

Camps are sources of potential damage not only to their own people but also to the inhabitants of the district wherein they are located, particularly to those who dwell down stream in the same valley. Pollution of a public water supply, either direct or through injury to its general water-shed, may become serious unless guarded against by competent sanitary supervision.

This supervision may be undertaken by those in responsible charge of the camp or else by the sanitary authorities of the municipality threatened. It would be better if it were carefully looked after by both, although it often fails to receive the attention of either.

There is abundance of law upon the statute books wherefrom the local health officer can draw all the power needed to meet the situation, but it too frequently happens that the power is not evoked until the threatening menace has developed into an actual disaster. The public itself should not be required to look into matters of health protection, for the sufficient reasons that they do not possess the skill and have, moreover, delegated a presumed expert to do that sort of work for them; consequently many sanitary sins will be overlooked, particularly if rectification should call for heavy demand upon the treasury.

When something serious does happen, however, the public energy will act with great vigor to abate an existing and manifest evil, even though the ounce of prevention that could have saved the day was at an earlier period considered an unnecessary expense.

Of all the forms of danger which may accompany camp life, that arising from the presence of human dejecta is the one requiring the most serious consideration. How shall this material be handled so as to deprive it of power to become a menace to health?

Even when the number of men employed upon a job is small, it will never be wise to allow them free license to act as they see fit in the matter of disposing of their bowel discharges. This is particularly true if the job be one involving the possible pollution of a public water supply.

So simple a device as a "straddle trench" is quickly made and easily cared for and, if well located, possesses the advantage of placing the material collected in a portion of the soil where pathogenic bacteria will find conditions least likely to favor their longevity.

As illustrating the great difference in numbers of ordinary bacteria found at sundry depths, the following counts are given per gramme of dry meadow soil:

Immediately under the sod	114,000
1 foot below	47,800
2 feet below	39,000
3 feet below	9,500
4 feet below	6,700

A straddle trench should be dug twelve inches wide, twelve inches deep, and as long as circumstances demand. Dejecta placed therein and covered at once with the excavated earth will be quickly destroyed, in contrast with what happens to it when deposited in pits many feet deep. In the latter case the action is one of imprisonment rather than destruction.

Anyone who has had occasion to uncover very old and large privy pits will recall the exceedingly foul condition in which the contents were found, even after the lapse of many years, while, on the other hand, the appearance of the soil turned by the plough in any field which has been repeatedly manured will furnish illustration of how quickly animal droppings will disappear after shallow burial.

It would seem scarcely necessary to urge attention to the selection of a proper site for a straddle trench, and yet it was lack of good judgment in such a matter that caused an outbreak of typhoid fever in a New England community through the washing out by heavy rainfall of dejecta carelessly buried on a steep hillside.

It takes but little infected material to produce great damage if the point of its introduction be a vital one. This was in-

stanced at Plymouth, Pa., when the dejecta of a single typhoid patient caused the illness of over twelve hundred people. Nevertheless, it is manifestly wiser to take chances on a little rather than on much of a dangerous article, particularly if that little be so distributed as to encounter conditions favorable to its destruction.

If the dejecta in the Plymouth case, instead of being accumulated upon a steep and rocky hillside during a northern winter, had been scattered upon a flat and sandy southern soil, the polluting material would have been easily and safely disposed of and no disaster would have occurred.

No more safe method of disposal for small amounts of night soil can be secured than placing it in small lots just under the surface of the ground in a level sandy loam. It is the privy system at its best.

How the ancient Hebrews looked upon this matter may be judged from the following: "Thou shalt have a place also without the camp, whither thou shalt go forth abroad: And thou shalt have a paddle upon thy weapon; and it shall be, when thou wilt ease thyself abroad, thou shalt dig therewith, and shalt turn back and cover that which cometh from thee." Deut. 23: 13.

Perhaps it may be not generally known that a device has been under trial by one or more railroads whereby a certain speed has to be attained by the car before the toilet pans can be dumped. While the train is standing at stations or while it is slowly approaching or leaving them the pans are automatically locked. The advantage, so far as cleanliness of the stations is concerned, is apparent, but benefit reaches further than that, for the reason that the material discharged at a high rate of train speed is spread over much ground, which increases the opportunity for natural purifying agencies to do their work.

A simple, old-fashioned privy system is often the only one which will fit camp conditions, but deep pits are then usually a necessity. Flies must be absolutely excluded from the possibility of reaching the excreta, seat covers must always be provided and must be so constructed as to be self-closing when the seat is vacated, and the ventilating window must be screened. The seat box should be movable to allow of the pit being burned out with straw and oil three times a week, if not oftener.

As camps grow in size the labor of properly caring for them

increases. Men have to be employed whose entire time is devoted to sanitary work. Proper water carriage of sewage, night-soil removal, and incineration of garbage are matters that fall under the care of such men.

A complete water-closet system contemplates sewers and also a disposal plant, unless there be available either some large body of water into which raw sewage can safely be discharged, or else an almost unlimited area of suitable sandy soil for disposal by irrigation. At one of our cantonments where some thousands of men are collected the raw sewage, after coarse screening, is run into a blind ditch in the sand, which ditch is simply extended as its side slopes and bottom becomes clogged. Clogging is delayed by suitable use of a rake. Nothing could be simpler, but the character of the soil requisite for such a solution of the sewage problem is rarely found, and when found cannot be unduly overworked.

The most novel proposition, involving a serious overload, that the writer ever encountered had to do with sewage disposal in a town in the Far West where deep wells were available which delivered much water under heavy pressure. The proposition was to use this artesian water to shoot the sewage into the air and thereby so distribute it over the country as to render it unobjectionable. One can imagine the state of things that would have resulted had such an odd plan been adopted.

A sewage disposal lay-out of a municipal type cannot be considered for a camp except under circumstances of decided permanency and when provision is to be made for a large body of men. At a number of our present military establishments we possess such systems of treatment, but labor camps are nearly always in quite another class.

Night-soil removal, or the can system, involves burying the can contents or else burning them, and the decision is sometimes in favor of employing both methods, although burying is the more common. There is an often-expressed objection to the burning of this sort of material because of a fancied unpleasant smell resulting, and yet it is really hard to detect any real difference between the odor so produced and that evolved by the combustion of almost any kind of organic material. Major Lelean quotes an interesting letter from a lady who wrote as follows: "The odor of burning peat, so delightfully reminiscent of the cotter's hearth,

becomes the intolerable effluvium of burning matter of an indescribably objectionable nature" when excreta are being burned. Inasmuch as the letter of objection was received when a wood fire was employed to try out the furnace, and before any excreta had been added, the Major was induced to seriously discount subsequent objections.

Many types of incinerators are in use, some of which are decidedly complex and expensive.

For a simple device, calculated to provide for a reasonable number of men, and especially suitable for garbage destruction, the Woodruff pit is worthy of attention. It is merely a circular hole in the ground, ten feet in diameter and about four feet deep, with the sides lined up with field stones. In the centre is a conical pile of the same stones to act as a sort of draft chimney. This pile can be advantageously supplemented by a couple of lengths of tile pipe or even old stove pipe. A good fire of wood having been started in this pit, a very considerable amount of camp refuse can be disposed of by judicious firing. Liquids should be slowly poured down the hot side stones so as to encourage rapid evaporation. If liquids be added in too great a bulk or thrown on too quickly they are likely to pass the fire zone and reach a lower level where they may start a nuisance.

One disadvantage of the Woodruff pit or of any other type of open fire is that when the wind is high light materials will often be blown about the camp; this is especially objectionable if the said materials chance to be what are known as "camp butterflies" or toilet paper.

Urine can be well disposed of by the stone-filled soakage pits, adopted by the British Army, into which long funnels of wood or tin are extended. Fouling of the ground with consequent fly infection is thus avoided.

At one large New York camp a non-portable furnace was built which worked successfully. It consisted of three levels, of which the bottom one held the fire. The top level was a shelf extending from the front half-way or more toward the back wall, and upon this shelf was thrown the material to be destroyed. The middle level was also a shelf of about the size of the top one, but it extended from the back wall out toward the front. Thus the hot products of combustion followed a curved course under and over the materials on the two shelves. When the charge on

the top shelf had become thoroughly dried it was pushed back so as to fall on the middle shelf, and when it had thoroughly charred in that position it was pulled forward and fell upon the fire.

A military furnace may be seen at Plattsburg which is operated without drying shelves. Its length is greater than its height, and the garbage charge is dumped directly upon the fire through a trap-door. The fuel is cord wood. Around the sides of the combustion chamber run iron water pipes that act like the water-back of a kitchen range and supply hot water with which to wash the cans in which the garbage is collected. The process is not continuous, and a new fire has to be started every morning.

While garbage is usually incinerated in a furnace such as this or in a Woodruff pit or in some still simpler arrangement burning either wood or coal, yet it generally contains so much combustible material that a device less costly in the matter of fuel consumption is to be preferred.

The Canadian camps, or at least some of them, are using a furnace, called the Reid incinerator, which is designed to operate continuously without any other fuel than that contained in the garbage itself after an initial fire of wood has been built as a starter.

In this type of apparatus a supporting grate-like set of bars is provided which suspends the garbage load and counteracts tendency to clogging. A further peculiarity of construction is a number of drawer-shaped draft holes which may be opened or closed at will, and which admit air to sundry well-spaced points throughout the body of the garbage charge.

The successful running of the Reid incinerator demands that enough garbage be supplied to keep the apparatus working on approximately full capacity.

Colonel Nasmith, of Toronto, advises the writer that while at the front in France excellent results were secured by constructing incerator walls out of old oil cans filled with puddled clay. After a wall built in such a manner had been fired it proved very stable. Similar cans used empty produced a reliable chimney and old railroad iron thrust irregularly through the furnace walls supplied supports for the garbage charge and permitted air to reach scattered points throughout the mass.

Doctor Nasmith found advantage to follow the introduction of old tin cans of every description into the furnace with the

garbage, as thereby a desirable "porosity" was given to the material being burned.

Horse manure can be burned by arrangement such as just described, but the destruction of valuable fertilizing material savors of decided waste, and, moreover, a labor camp rarely contains enough horses to demand military measures.

Fifty horses will make about a wagonload of manure daily, but, however small the volume may be, provision must be made to prevent its becoming a breeding place for flies. Usually, although not always, farmers are found willing to cart manure away for use upon their crops, in which case it is of interest to be certain that it is hauled to a sufficient distance before it is piled; otherwise, as a large camp presents many attractions for flies, the insects are likely to find it if the haul should be a short one. Major J. M. Phalan, U. S. A., believes that the only safe haul is one by railroad, for the reason that a distance likely to be covered by ordinary wagon hauling would probably prove much too short to prevent the flies reaching camp.

However much the average farmer may value good manure which is given to him, the labor camp is frequently so placed as to make the use of its horse droppings for fertilizer unprofitable because of the expense of removal. A small amount of manure can be made "fly-proof" by a liberal wetting down with solution of copperas, but a much better treatment is that of destruction by fire. Windrows less than two feet high can be successfully burned if sprinkled with crude oil.

Before leaving the question of flies we should remember that a single insect can produce nearly a million descendants during a season. They feed to a large measure upon fæces, and their bodies and legs are covered with hairs, so that they can act as distributers of pathogenic organisms by vomiting upon human food, by defecating over it, and by wiping their filthy feet upon it.

So much has been written upon the necessity of protection against flies and mosquitoes that it is simply needed here to insert a reminder that the development period, from egg to mature form, of each of these insects is practically the same; namely, about two weeks. Precautions in the way of thorough screening of quarters, removal or destruction of horse manure, and oiling or draining of water pools, however small, must be faithfully practised throughout the breeding season.

Only a word can properly be said here upon the general subject of "housing," because upon that topic there are far too many variables to allow of a fair standardization of labor camps. Five hundred cubic feet of air space per man should be supplied in the sleeping quarters, and mosquitoes should be excluded by careful screening.

Each camp must be treated upon a plan of its own and local conditions must govern. The construction of proper ditches to receive roof drip and the use of the material excavated from these for "banking" the outer walls against drafts along the floor naturally suggest themselves as suitable procedures.

Sleeping accommodations of the "bunk" form are more compact and are cheaper than cots placed side by side. They have the disadvantage of being more difficult to keep clean than the open arrangement, but, on the other hand, communicable diseases are not so easily transmitted under crowded conditions.

Both one-story and two-story barracks have their advocates. The two-storied forms are certainly cheaper to heat per capita, and they are also less expensive in the matter of cost of roof construction, calculating upon the same basis.

The following description by Meriwether of prison barracks may be inserted here:

"They occupy what are called Adrian barracks, which are built of wood, in sections one hundred feet long by twenty-five feet wide. The necessary parts are standardized and can be quickly assembled. After each big battle a quantity of the parts is rushed to the desired point, and within a few hours accommodations are ready for the captured men. On the day of our visit the camp contained eleven hundred and ninety-eight prisoners, but three hundred and sixty more were to arrive the next day, and quarters for the newcomers were being assembled.

"Each barrack contains two rows of two-story bunks, the upper bunk being placed four feet above the lower. In the centre between the two rows of bunks is an aisle provided with long tables and benches. Electric lamps light this centre aisle, and the prisoners use the tables as dining-tables and for playing games and writing letters.

"In another the grounds of the camp were drained by subsoil pipes. The wooden barracks, heated by stoves and lighted by electricity, contained bunks raised eighteen inches above the

wood floors. Each bunk was provided with a straw mattress and two woollen blankets."

Camps being but temporary in character, a due consideration of the "economic period" for which they are built naturally controls to a large degree the design of the quarters.

In localities of special danger, as when new construction or repairs are in progress in the immediate vicinity of some public water supply, the care exercised in the camp itself must be extended to the site of the work as well. The thoughtlessness that a labor gang can exhibit upon occasion is simply amazing.

It would seem sufficiently careless to deposit fecal matter upon the steep bank of a stream a short distance above a city intake, but the writer has seen the same material dropped in the open end of a cast-iron water main as it lay in the ditch. Nothing but careful sanitary supervision can meet such abuse.

Naturally the officer in charge of formulating the rules governing the camp, if worthy of his responsibility, would see to it that the regulations were suited to the local conditions and, while strict enough to safeguard health, were not so loaded with unnecessary caution as to become a burden. No hard-and-fast rule can be laid down which will state, for instance, the exact point beyond which pollution will become dangerous and short of which one can count upon safety. The writer had upon one occasion testified that five thousand head of cattle would seriously damage the water of a certain stream upon the banks of which they were corralled. The cross-examiner asked if twenty-five hundred would likewise cause serious pollution, and the answer was "Yes." The next question was, "Would twelve hundred cattle produce serious pollution?" To this the reply had to be made that "while willing to halve the number of cattle actually covered by the facts in the case at issue, it would be unwise to attempt further division, for fear of finding a single cow polluting the entire valley."

The prominence usually given to what may be termed the auto-intoxication of a camp may well mask the equally important matter of the danger a camp may be to the well-being of those whose homes are in the same drainage area. Camps are, of course, of all sizes, depending upon the magnitude of the job, but it is no error to assume that for the same quantity of proposed work a larger number of laborers must now be provided than

were needed for the same work a few years ago. As an instance, it was formerly common on railroad construction to find four men carrying a hundred-pound rail, where now twelve are demanded; and, while one man could in the past shoulder a railroad tie, it now must be lifted by two men, one at each end, except in those cases where the tie is creosoted, when four men using lifting tongs are required.

Of course, such circumstances increase not only the expense of construction but they also call for greater vigilance to provide against sanitary risks arising from enlarged camp population.

Nothing short of conscientious sanitary inspection, followed by promptness in necessary action, can meet the difficulties that confront those in charge of water-shed protection.

It is of the utmost importance that engineers and foremen should remember that in a very real sense they are health officers and sanitary instructors as well. The men under their care are likely to be largely ignorant of elementary sanitation and need both instruction and advice. If the camp be sufficiently large to support a meeting hall, great good will follow the inauguration of lectures and instructional moving pictures. Not only needed information is thereby supplied, but entertainment also.

It goes without saying that the camp water supply is a matter of major importance, and it is the manifest duty of the parties in charge to so arrange matters that a suitable volume shall be always available and that its quality shall be suitable as well. Small groups of men can usually be safely supplied locally, but large camps may demand the exercise of considerable skill of a special character to meet their needs. No haphazard guessing nor the application of household tests should be employed to determine the suitability of a water for use in a large camp. At this point we are reminded of a quaint old book by John Smith, printed in 1712. Its title is "The Curiosities of Common Water, or the Advantages Thereof in Curing Cholera, Intemperance, and Other Maladies." In it we note: "How to distinguish water." "The way to do this is by the taste and scent—for if it have no taste nor smell, being purely fresh, nor salt, nor sweetish, nor ill-scented, it is good, provided it be pure and clear." "All water that will make good lather with soap is wholesome to drink without boiling, but none else."

It may be that no little difficulty will be encountered in persuading the men to avoid the attractive water from some polluted well and use the safer camp supply, as the latter may have been carried some distance in slightly buried pipes and consequently be lacking in coolness. If the camp water should have a taste due to algæ, there would be still greater difficulty in securing its use. Algal taste can be successfully removed by a small dose of potassium permanganate, as first proposed by Houston. Removal of the means of raising the water from an open and polluted well is the best plan for stopping its use if such a procedure be permissible. Deep or driven wells furnish supplies that may be nearly always accepted with confidence.

Bathing should be encouraged, and, unless the camp be very small, showers of simple construction should be built. In the absence of showers, abundant provision should be made for the washing of both body and clothes, and no charge should be made for soap.

To insist upon and secure periodical bathing is rather more than those in charge of labor camps can accomplish; all they can do is to see to it that provision is made for maintaining cleanliness and leave the rest to the discretion of the men. Fifty gallons of water per day per capita should be supplied to large camps; this will very liberally suffice for all purposes.

It is interesting to observe the economies that have to be practised during the present war in localities where water is scarce: thus we note in the *Journal of the Royal Army Medical Corps*, 27: 363: "Baths at the front where water is scarce. Add lime to the water after use and mix by hand power. Insoluble lime soap separates, settles, and carries down impurities. Settlement is effected in three successive concrete tanks. Sodium carbonate is added to the water in the third tank, whereby calcium carbonate is precipitated and oils are caused to float. The latter are absorbed by sacking on frames. After settling in this third tank, the water is passed through a charcoal bed four inches thick." The water treated as above is described as quite clear and "free from dirt, soap, lime, and soapy oils." The same water is used indefinitely.

As to the character of the pipe for camp plumbing and the possibility of its being acted upon by the water carried, there is not the same necessity for careful selection as when more per-

manent construction is being undertaken. "Red water," due to an attack upon iron by a soft surface supply, is not likely to appear immediately, so that even an inferior galvanized pipe will probably last long enough to outlive the purposes of the camp, and we know that action upon the protecting coating, whereby zinc is carried into solution, will cause no injury to those drinking the water. Large amounts of zinc have been swallowed by sundry communities over long periods of time without ill effects. Thus Hazen reports that at Brisbane, Queensland, the water, which is stored in tanks built of galvanized iron, contains over seventeen parts per million of zinc, yet no harmful effects have been observed after years of use. A number of city water supplies of Massachusetts have been reported by the State Board of Health as containing zinc, but no evil results due to its presence have been reported.

In the State of New York certain rules are formulated by the Commissioner of Health which work hardship to no one and which materially aid in conserving the health both of the camp and of the neighboring communities. Among the requirements, we observe that even for so small a labor camp as one holding ten people a permit must be secured if the camp site is to be occupied for over six days.

If there be twenty people in the camp, then a camp care-taker must be appointed.

No camp building of any kind shall be erected within fifty feet of a stream or lake furnishing public water supply.

Any privy located within from fifty to two hundred feet of said stream or lake shall be built without a vault and its dejecta shall be removed daily to a distance of at least two hundred feet from the water's edge before being buried or incinerated. A number of states have similar sanitary rules, but unfortunately others do not.

Engineers in charge of even large labor camps could scarcely be expected to have the camp cooks examined to determine if they were "typhoid carriers" or to provide "typhoid vaccination" for the men; neither could it be expected that they should look after the cleanliness of their employees to the extent of ridding them of body vermin, nor is it likely that the latter attention would be acceptable to the employees if it were offered.

A feeling of thankfulness should develop upon the thought that supervision does not have to extend so far, for the thorough

accomplishment of that kind of an undertaking is a task indeed. One has but to note the almost endless detail and yet perfect smoothness of running in the matter of managing that disagreeable job among the troops now in France in order to appreciate how much the commander in civil life is spared. To quote from a prominent military authority: "It takes from 8 A.M. to 4.40 P.M. to attend to the thorough 'de-lousing' of 1400 men. This includes washing of the bodies and the washing, steaming, and drying of their clothes."

To conclude, we see that the proper management of a labor camp is largely founded upon common-sense and good judgment, with an additional allowance of that extra sense called "tact," which enables one to get along efficiently and smoothly with other men.

A New Standard of Current and Potential. C. F. ALCUTT. (*Proceedings of the American Institute of Electrical Engineers,* vol. 37, No. 2, p. 83, February, 1918.)—The increasing use of potentiometers in commercial service, especially in connection with the measurements of temperature by means of thermocouples, makes it very desirable to secure a substitute for the standard cell usually required by these instruments. The serious shortage of standard cells caused by the war has emphasized this need. Furthermore, it is being recognized that it is poor economy to use a costly precision standard in a commercial potentiometer which reads to three significant figures at the most.

The new standard which is proposed as a substitute for the standard in certain classes of direct-current measurements is essentially a Wheatstone bridge which will balance for but one value of the current. The device consists of a Wheatstone bridge comprising three constant resistances, and a fourth element whose resistance is a function of the current flowing through it. In practice the resistance element consists of an evacuated glass bulb which encloses a fine filament of material having a relatively high temperature-coefficient of resistivity. The practicability of the device depends on securing a variable resistance having the desired current-resistance characteristics, together with a high degree of permanence. A bridge of this type was designed to balance with a current of 20 milliampères, and having just one volt potential difference when the bridge is balanced. The work done in connection with the development of this new standard has demonstrated that it may be relied upon to maintain an accuracy of plus or minus 0.1 per cent.

THE NON-MOLECULAR STRUCTURE OF SOLIDS.*

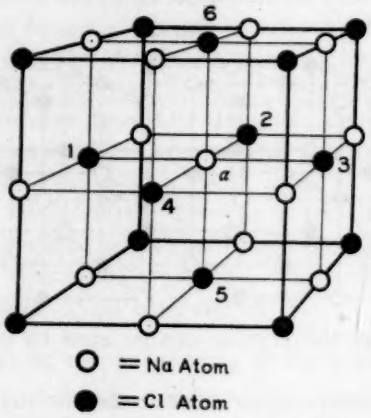
BY

ARTHUR H. COMPTON,

Research Laboratory, Westinghouse Lamp Company.

ONE of the most striking things in the structure of crystals as worked out by Prof. W. H. and Mr. W. L. Bragg † is the orderly manner in which the atoms of the different crystals are

FIG. 1.



arranged. The evidence of X-ray analysis points definitely to a structure in the simple crystals which have been examined in which there is no evidence whatever of any grouping of the atoms into molecules. It seems rather that the position of an atom depends equally upon all the neighboring atoms, so that the whole

* Communicated by the Author.

Contribution from the Research Laboratory of the Westinghouse Lamp Company, East Pittsburgh, Pa., January 5, 1918.

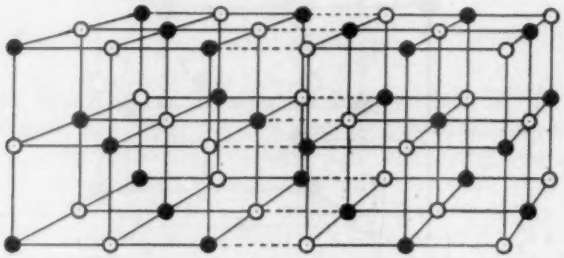
This paper was sent to three members of the Physics faculty at Princeton University on July 25, 1914. It was read before the Physics Colloquium of Princeton University on October 8 1914. Though not originally prepared for publication, the subject has become one of such general interest that it has been thought worth while to publish the article at this time without alteration.—THE WRITER.

† Proc. Roy. Soc., 1913–1914.

mass is a homogeneous bundle of atoms which have no tendency to form into molecules.

If we take, for example, a crystal of rock-salt, we find the atoms of sodium and chlorine arranged alternately in a simple cubic pattern (Fig. 1). Any one sodium atom *a* is equally strongly bound to any one of six chlorine atoms, 1, 2, 3, 4, 5, 6, or *vice versa*. It is evident that it is easy for the atoms to pair off into molecules on passing into the liquid state. In doing so, however, there are equal probabilities for an atom to combine with any one of six others, so that we cannot expect the same pair of atoms to form a molecule after the substance melts as were together before they assumed the solid state. Thus no particular

FIG. 2.



pair of atoms in the crystal can be said to belong to the same molecule.

In order to make more evident the absence of true molecular structure, let us consider a salt crystal to be made up of two cubes (Fig. 2), each cube having an odd number of atoms on its edge. Then the whole crystal has an equal number of sodium and chlorine atoms, but if it be split in the middle, one half will contain an excess of chlorine and the other of sodium atoms. Thus by the simple operation of splitting the crystal along a cleavage plane we must have performed the exceedingly delicate operation of mechanically severing a molecule into two parts—a chemical process—if there is a true molecular structure in the crystal. Exactly similar arguments show the non-molecular structure of the other kinds of crystals which the Braggs have determined.[1]

[1] So far as the writer is aware, the fact that the work of the Braggs thus indicates a non-molecular structure in the crystals which they examined was first pointed out by him in *The Scientific American Supplement*, July 4, 1914, page 5.

In these simple crystals, then, if the structure as determined by X-rays is correct, each atom is held in position equally by all the neighboring atoms. It is natural to suppose, therefore, that in substances which are chemically more complicated, as in these simple crystals, each atom is affected by forces equal, on the average on all sides, so that there will be no grouping into molecules. Thus by the definite indication by X-ray analysis of a non-molecular structure for certain simple crystals we are led to the idea that very possibly the structure of all compounds, however complicated, is non-molecular in the solid state.

We may therefore state the thesis that we hope to prove, thus: *Every atom in a solid has its position so determined by the other atoms that it cannot be said definitely to belong or not to belong to the same molecule as some other one atom.* That is, in the solid state the atoms of the substance are so intimately intermingled that particular molecules cannot be definitely defined. Since this proposition is apparently not in accord with the generally accepted molecular theory of solid matter, it is important to see how it is confirmed by a study of the general properties of matter as well as by the molecular theory itself. In this way we hope to form an argument which will show that *non-molecular structure is an essential attribute of all solid matter.*

ARGUMENT FROM THE PROPERTIES OF SOLID MATTER.

From an historical standpoint, the way in which the conception of molecules in the solid state was formed was by a deduction from the kinetic theory of gases. It was easy to explain the change from gas to liquid as due to a shrinking of molecular distances to something comparable with the diameter of the molecules, at which distance the molecules would be held together by intermolecular forces. Likewise the passage from the liquid to the solid state was explained as the settling of the molecules into positions of stable equilibrium. Since the molecules have a definite form in the gaseous state, it was natural to suppose that they would keep this form in the liquid and solid states. We have already seen, however, that there is no trouble with an explanation of the passage from the solid to the liquid state, even with a non-molecular structure in the solid. For example, NaCl, which is known to have a non-molecular structure, actually does melt, so that a molecular structure of the solid is not neces-

sary. The explanation of this we saw was simply that the atoms in the salt crystal paired off when assuming the liquid state. Since, therefore, a non-molecular structure accords as well with the general kinetic theory of gases and liquids as does a molecular solid, there is no *a priori* reason why solids should be molecular in structure.

It will be convenient, however, to speak of the atoms in the solid state as belonging to molecules, meaning either the molecules to which they belonged before assuming the solid state or those to which they will belong if they assume again the liquid or the gaseous state. We shall then employ a sort of *reductio ad absurdum* method, and try to show that these groups of atoms cannot exist in the solid as definitely defined molecules.

In order to prove the thesis as stated above, it will be necessary to show that at least some of the atoms of every molecule are bound as strongly to atoms of other molecules as they are to their own. It is evident that this means a non-molecular structure, since there can be no definable boundary to the molecules in such a case. We shall attempt to prove this point by steps, showing:

1. That each atom in a solid oscillates about a definite position of stable equilibrium.

2. That the forces holding the atoms in their positions of stable equilibrium are of the same nature and are comparable in magnitude with the forces binding together the atoms of the same "molecule"; and

3. That at each of the frequent collisions the forces between the atoms of different "molecules" become so great that an atom has even chances to be torn from the atoms of its own "molecule," so that, on the average, it is bound equally to all the neighboring atoms.

The evidence for the fact that each atom has a definite position in a solid is well known. In the first place it is a generally accepted part of the molecular theory that in the solid state the molecules are in positions of stable equilibrium from which they hardly move. The fact that a true solid will not change its shape under small forces even for great periods of time shows that the molecules are not free to move from place to place. Also, the existence of the latent heat of fusion and of sublimation shows that in the solid state the molecules are in positions of minimum potential energy and hence of stable equilibrium.

But we can show, also, that the molecules in a solid are arranged in definite directions as well as in definite positions, which means, of course, that the atoms are in definite positions. We shall point out below that the structure of all solids is crystalline, so anything which we prove for crystals will hold for all solid matter. Now it is evident that to form any regular crystal structure the molecules must be arranged in a regular order. But it is generally accepted that the crystal form is some function of the chemical constitution. Unless, however, the atoms in the molecule are arranged in a definite order, it is hard to see how the crystal form can be influenced by the chemical composition. As a matter of fact, a definite arrangement of the atoms in crystals is assumed in the explanation of many of the properties of matter. For example, Lord Kelvin, in explaining pyro- and piezo-electricity (Poynting and Thomson, "Electricity and Magnetism"), assumes that the molecules in the crystals which show this effect have their parts arranged in a certain definite manner, as described below (p. 27). Likewise Bridgman, in explaining the phenomenon of polymorphism under high pressures, says (*Phys. Rev.*, iii, p. 199): "It seems natural that the crystalline form assumed under the free action of the orienting forces is one in which the potential energy of the attractive forces is a minimum; that is, that the local centres of attraction within the molecule have approached as close as possible to each other. If the molecules are forced to assume a different arrangement, even one occupying less volume, these centres of attraction must be pulled apart, and work done against the attractive forces while decreasing the volume. That is, the internal energy of the form with the smaller volume will be the greater." Also, it may easily be shown that the explanation of the expansion of certain substances on solidification depends upon the existence of local centres of attraction within the molecules. It is possible to imagine systems in which the arrangement which would bring the local centers of attraction nearest together would not be the arrangement of minimum volume, so that when the molecules would be in stable equilibrium the volume might be a maximum. Indeed, it is difficult to see how there can be any other explanation. These local centres of attraction, however, can be nothing other than atoms or groups of atoms. We shall see below (p. 11) that if the orienting forces are the attractions between the atoms, such a position of

the molecules in the solid state is very easily accounted for. It seems evident, therefore, that in order to explain the crystal structure the molecules must be oriented in such a manner as to give to each atom a definite position.

Aside from this evidence that atoms in crystals have their positions defined, we have further evidence that the atoms in any solid oscillate about definite centres of stable equilibrium. According to the theory of the equipartition of energy, each degree of freedom of an atom in the solid state should possess the same average kinetic energy as a degree of freedom of an atom in the gaseous state at the same temperature. But if we give to each atom in the solid state three degrees of freedom, the specific heat of the atom calculated from the rate of increase of the kinetic energy is only half that which corresponds to Dulong and Petit's law for the atomic heat. Since an atom is supposed to have but three degrees of freedom, in order to account for this difference it is necessary to ascribe to each degree of freedom of the atom potential energy as well as kinetic energy, which increases as the temperature, to give the atom the proper amount of specific heat. But the existence of this potential energy means that the atom is vibrating about a position of stable equilibrium. As the kinetic energy of the atom accounted for half the specific heat, the potential energy must account for the other half, and must therefore be equal, on the average, to the kinetic energy. This indicates that the motion of an atom is, in general very nearly harmonic motion about a central position.

In the explanation of heat radiation, also, we have an indication that the atoms oscillate about centres of stable equilibrium. The explanation referred to is the common one that in solids heat waves and long light waves are produced chiefly by the oscillation of the atoms in harmonic motion about positions of stable equilibrium. Thus from two different lines of evidence we come to the conclusion that the atoms in any kind of a solid must oscillate about positions of stable equilibrium.

THE NATURE AND MAGNITUDE OF THE INTERMOLECULAR FORCES.

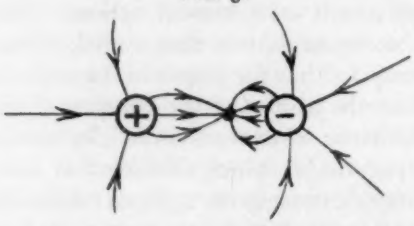
The next question is, What is the nature of the forces which hold the atoms in position? This will become evident as we discuss the phenomenon of the cohesion of solids. The accepted molecular theory explains cohesion as due to the settling of the

molecules into positions of stable equilibrium, where they are held by the intermolecular forces. It is evident, on the kinetic theory, that the collisions of each molecule with the neighboring molecules will be very frequent in the solid state. But we can show that when two molecules are in "contact" the attraction between atoms of the different molecules is of the same nature and of the same order of magnitude as the attraction between the atoms of the same molecule. This is evident from a consideration of the forces which occur in chemical action. For instance, the fact that some compounds are dissociated when they are dissolved in water implies that the atoms in the water molecules exert a greater force on the atoms of the compound than these do on each other. Similarly when two molecules interact directly, as in an organic reaction in which dissociation takes no part, the atoms of one molecule must exert a greater force on certain atoms in the second molecule than do the other atoms of the second molecule. In fact, the universality of reversible reactions shows that in every case there is a delicate balance between the forces binding an atom to its own molecule and the forces tending to make it join the molecule with which it is in contact. There can be little doubt, therefore, that at least while two molecules are in contact the forces between their atoms are not only of the same nature but also of the same order of magnitude as the forces binding together the atoms of a chemical molecule. (It might be thought at first that this theory of attraction between the atoms of different molecules is opposed to the theory of chemical valency which would seem not to allow an atom to attract more other atoms than it has chemical bonds. According to Stark's theory (Campbell, "Modern Electrical Theory," p. 341), which is possibly as good as any explanation yet offered of the mechanism of valency, a chemical combination between two atoms is not a direct attraction of one atom for another, but a simultaneous attraction of both atoms for the same electron, which thus forms a bond between them. This common electron is one which originally belonged to the electropositive atom, but which was more strongly attracted by the electronegative atom, and on being brought nearer to this atom has the effect of giving it a negative charge and of giving the electropositive atom a positive charge. This method of binding may be illustrated by Fig. 3.

(According to Stark, the band spectra of substances represent

the vibrations of the electrons concerned in chemical combination, which are, of course, these "valency" electrons. The fact that the spectrum bands widen as the pressure of the gas increases indicates that these electrons are influenced by neighboring atoms as well as by the atoms of their own molecule. This suggests that the valency electrons may not be fixed in position, but that their positions may be altered by the presence of other molecules.

FIG. 3.



So, if another molecule should come near the first, we might expect them to be held together in some such manner as shown in Fig. 4.

(Since the electronegative atom acts as though negatively charged, and the electropositive atom as though positively charged, on account of the position of the valence electron, it is easy to see how a whole system of atoms may be held together, due to

FIG. 4.

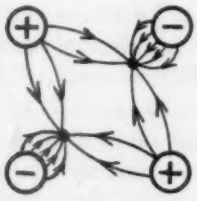
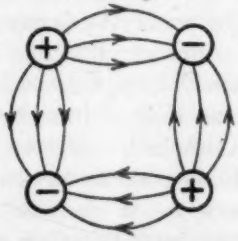


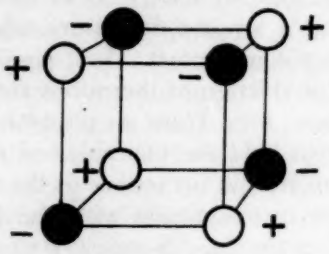
FIG. 5.



the electrostatic forces. For example, when two molecules composed of oppositely charged atoms come together, a position of stable equilibrium is as illustrated in Fig. 5. If two more come near, a position of stable equilibrium is as shown in Fig. 6, which is the elementary cube of an alkali halide. It seems probable that if the equivalent charge and the diameter of every atom were known it might be possible in this way to calculate the different crystalline forms of every compound.)

Since, therefore, we know that the forces between atoms of different molecules are of the same nature and of the same order of magnitude for at least a considerable portion of the time as those binding a molecule together it is natural to assume that these forces are always similar. Evidence that the forces between the atoms of different molecules are, in general, comparable with the forces between atoms of the same molecule results from a consideration of the atomic heat of substances in the solid state. We found above that in order to explain the specific heat of an atom in the solid state it was necessary to assign to it three degrees of freedom. This is true in whatever way the atom may be combined chemically, so long as the substance obeys Kopp's

FIG. 6.



extension of the Dulong-Petit law. According to the Staigmüller-Boltzmann theory, however, in the gaseous state an atom has no degrees of freedom along its chemical bonds. In order, therefore, that in the solid state it shall have three degrees of freedom, the attractions of the atoms of the neighboring molecules must loosen the chemical bonds enough to allow other degrees of freedom. But in order to do this these attractions must be at least of the same order of magnitude as the forces binding the atom to its own molecule.

If, as we have assumed above from a consideration of the Dulong-Petit law, an atom in the solid state has degrees of freedom along its chemical bonds, an atom on the surface of a solid ought, according to the law of velocity distribution, to break away occasionally from the solid as in sublimation. A single atom subliming in this manner should carry with it either a posi-

tive or a negative change,[2] so that we should expect the vapor from a subliming solid to be partially ionized. The proportion of the ionized atoms would, of course, be relatively small, since it would be much easier for a group of atoms forming a gaseous molecule to leave the solid than for a single atom, which would be held back by an opposite charge in the solid. Moreover, even though an atom in the *interior* of the solid may have three degrees of freedom, it is easily possible that at the *surface* of the solid, since all the attractions are from one side, the atom might be held firmly to the other atoms so as not to be free to escape. If this be true, it should be possible to show that in the form of very thin foil a substance has smaller specific heat than when in lumps. But even in this case it would seem that an atom on the surface of a solid should not be held as firmly along its chemical bond as it would be in the gaseous state. So we should expect a vapor to become ionized at a lower temperature when in contact with its solid than when not in contact. Is it possible that this is the explanation of the production of thermions from hot salts?

There is evidence, also, from an altogether different source that the forces which hold the molecules of a solid in positions of stable equilibrium are the attractions of the neighboring atoms, and are comparable in magnitude with the forces between the atoms of the same molecule. A measure of the forces holding the atoms together in a molecule is the total heat of combination. Also, since a substance melts when its molecules attain kinetic energy enough to tear them away from the neighboring molecules, the melting-point may be taken as a rough measure of the firmness with which the molecules are held together in the solid. We should expect, therefore, if the firmness with which the molecules are held together depends upon the same properties of the atom as the firmness with which the atoms are held together in the molecule, that the melting-point should vary roughly as the heat of combination.

In order to test this prediction fairly it must be remembered that the melting-point of a solid must depend to some extent upon

[2] This statement, of course, assumes that the substance is a polar compound, in which case the atoms carry electric charges. If the combination is non-polar, no such evaporation of ions could occur. This is possibly the reason why the emission of thermions of atomic size is confined to the strongly polar compounds, such as the alkali and alkaline earth halides.

the arrangement of the atoms in the molecule as well as upon the magnitude of the attractions between the different atoms. Also, it seems very probable that at the melting-point only a definite proportion of the molecules escape from positions of stable equilibrium, the rest remaining in small groups forming "liquid crystals." (This is the explanation that is given for the expansion of water below four degrees. The high specific heat of liquids in general may be explained as due to the latent heat of fusion of these "liquid crystals" as they melt with rising temperature.) It is probable that the relative number of molecules which have sufficient kinetic energy to escape from the positions of stable equilibrium is different for different substances at their melting-points, which would also indicate that the melting point is only a rough measure of the stability of a molecule in a solid. Moreover, the heat of combination is not an absolute measure of the stability of the molecule, for, in the first place, this varies with the stability of the different atoms in the elemental state; *e.g.*, CO_2 from amorphous carbon has a heat of formation of 97.3×103, while from diamond it is only 94.3×103. In the second place, the heats of formation of substances differ relatively at their melting-points and at room temperature. In view of these and other disturbing factors, we have no reason to expect more than a rough agreement between the atomic heats of formation and the melting-points of the different substances.

In testing this prediction I have grouped similar compounds together, since one would expect that the atomic arrangement of such compounds in the solid state would be similar (see Table I).

TABLE I.

Showing Relation Between the Melting-points (m.p.) and the Atomic Heats of Formation (A.H.F.) of Various Substances.

(*A*) ALKALI HALIDES, ETC.

Substance	A.H.F.	m.p.	Substance	m.p.	Substance	m.p.
KCl	53×10^3	770	KBr	750	KI	723
NaCl	49	801	NaBr	765	NaI	695
LiCl	47	600				
HgCl	15.5	500				
AgCl	14.5	460	AgBr	427	AgI	540
HCl	11	−111	HBr (4)	−86	HI (−3)	−51

(*B*) BICHLORIDES, BROMIDES AND IODIDES.

Substance	A.H.F.	m.p.	Substance	m.p.	Substance	m.p.
($BaCl_2$		960)	$BaBr_2$	880	BaI_2	740
$SrCl_2$	62	825	$SrBr_2$	630		
$CaCl_2$	57	780	$CaBr_2$	760	CaI_2	740
$MgCl_2$	51	708				
$BeCl_2$		600	$BeBr_2$	601		
$PbCl_2$	28	447				
$HgCl_2$	18	290	$HgBr_2$	244	HgI_2	241
$CuCl_2$	17	498				

(*C*) TRI-HALIDES.

Substance	A.H.F.	m.p.	Substance	m.p.	Substance	m.p.
$BiCl_3$	23	227	$BiBr_3$	215		
$SbCl_3$	23	73	$SbBr_3$	93	SbI_3	167
$AsCl_3$		−18				
PCl_3		−112				
$FeCl_3$	24	301				
$AlCl_3$	$24+10^3$	301	$AlBr_3$	93	AlI_3	185
$GaCl_3$		73				
$TlCl_3$		25				

(*D*) ALKALI, ETC., SULPHATES, CARBONATES AND NITRATES.

Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.
K_2SO_4	49	1070	K_2CO_3	47	880	KNO_3	24	345
Na_2SO_4	47	884	Na_2CO_3	45	849	$NaNO_3$	22	313
Li_2SO_4	48	853	Li_2CO_3		710	$LiNO_3$	22	258
Tl_2SO_4	32	632						
H_2SO_4	27	10.4				HNO_3	8	−47
Ag_2SO_4	24	676				$AgNO_3$	6	218

(*E*) ALKALI-EARTH, ETC., SULPHATES, CARBONATES AND NITRATES.

Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.
$BaSO_4$		infus.	$BaCO_3$		795	$Ba(NO)_2$		575
$CrSO_4$		dec. w.ht.	$SrCO_3$	dec.	1160	$Sr(NO_3)_2$		645
$CaSO_4$	53	v. high	$CaCO_3$	54 dec.	r. ht.	$Ca(NO_3)_2$	27	561
$PbSO_4$	38	937				$Cu(NO_3)_2$	9	114.5

(*F*) OXIDES.

Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.	Substance	A.H.F.	m.p.
MgO	71.5×10^3	over 2000	Cu_2O	14	rd. ht.	SO_3	26	14.8
SiO_2	60	1600	NO_2	−.6	−10	H_2O	23	0
P_2O_5	53	subl. r. ht.	N_2O	−6.3	−102	CO	14.5	−207
Al_2O_3	30	wht. ht.	CaO	70	infus.	Bi_2O	4	84
PbO	25	rd. ht.	B_2O_3	55	577	Cl_2O	−6	−19
SO_2	23	−76	CO_2	32	−65	NO	−11	−167

(*G*) OXIDES AND SULPHIDES.

Substance		m.p.	Substance		m.p.	Substance		m.p.
Sb_2O_3		rd. ht.	H_2O	(23)	0	Bi_2S_3		decomp.
Sb_2O_5		300	ZnO		V. high	CS_2	(−6)	−110
Bi_2O_3		860	Sb_2S_3		fusible	H_2S	(1)	−86
CO_2	(32)	−65	Sb_2S_5		fusible	ZnS		1050

The heat of formation used is that of a gramme-molecule, divided by the number of atoms, thus giving what may be called the "atomic heat of formation." It will readily be seen, by a glance at the tables, that in general the higher the heat of formation the higher the melting-point of a substance. There are a few exceptions to the rule, but the discrepancies are small, and there can be no doubt that the rule holds in general. For instance, if we take the alkali chlorides, the decrease in melting-point is regular, except for a slight variation in sodium, and so, also, as we pass from the chlorides to the bromides and iodides; similarly with the sulphates, carbonates, and nitrates. Among the oxides there are a great number of exceptions, but the predominance of high melting-points at the head of the list and of low melting-points at the foot shows that the general rule holds. Moreover, when the sulphides and the oxides are compared, the former invariably have the lower melting-point, as they should. In order to show that these uniform results are not confined to elements of the same periodic group, Table II and the graph with it have been made, showing all the compounds in the order of their

TABLE II.

The Melting-points of Different Substances in the Order of Their Atomic Heats of Formation.

—Substance	A.H.F.	Authority	m.p.	—Substance	A.H.F.	Authority	m.p.
			C°				C°
ThO_2	110 ×10³	3	infus	B_2O_3	55	1	577
UO_2	85	5	2176	TiO_2	54		1500
Al_2O_3	79	1	2040	$CaCO_3$	54	2	1289
MgO	72	1	>2000	$CaSO_4$	53	2	>1000
CaO	70	1, 2	1995	P_2O_5	53		*850
$BaCl_2$	66	2	960	KCl	53	1, 2	770
SrO	65	1, 2	3000	$MgCl_2$	51	2	708
V_2O_5	63	5	658	K_2SO_4	49	1, 2	1070
$SrCl_2$	62	1, 2	825	NaCl	49	1, 2	801
SiO_2	60	1	1600	$LiSO_4$	48	2	853
ZrO_2	59	7	2500	WO_3	48	7	*800
$CaCl_2$	57	2	780	Na_2SO_4	47	1, 2	884

*=approximate value.

TABLE II. (*Continued*)

—Substance	A.H.F.	Authority	m.p.	—Substance	A.H.F	Authority	m.p.
			C°				C°
LiCl	47	2	600	CuO	19	2	1148
K_2CO_3	47		880	$HgCl_2$	18		290
MnO	45		*1500	$CuCl_2$	17		498
Na_2CO_3	45	1, 2	849	HgCl	15		500
MoO_3	45	5	759	CCl_4	15	1	− 24
As_2O_5	42	2	960	Cu_2O	14		*800
Fe_3O_4	40	4	1538	Tl_2O	14		*700
Fe_2O_3	39	18	1458	AgCl	14	1, 2	460
$PbSO_4$	38	2	937	PbI_2	14	6	373
$CdSO_4$	37	2	>1000	CO	14		−207
LiOH	37		*850	C_2H_3COOH	11	2	− 22
KOH	35	1, 2	360	HCl	11	2	−111
NaOH	34	1, 2	318	$Cu(NO_3)_2$	9		114
FeO	32	18	1419	AgI	8	13	500
K_2O	32		*800	HNO_3	8	1	− 47
Na_2O	32		*800	CH_3OH	8	2	− 95
Tl_2SO_4	32	2	632	Trifluorocresol	7	17	− 5
$ZnCl_2$	32	1, 2	375	C_2H_5OH	7 ×10³	2	−112
CO_2	32	1, 2	−65	CH_3CHO	7	2	−120
TeO_2	29	5	*600	$AgNO_3$	6	1, 2	218
Co_3O_4	28	5	750	Nitrofluorophenol	5	17	74
$PbCl_2$	28	2	447	$CHCl_3$	5	2	− 70
$Ca(NO_3)_2$	27	1	561	$(C_2H_5)_2O$	5	2	−117
$SnCl_2$	27	2	249	Fluoronitracetanilide	4	17	96.5
H_2SO_4	27	2	10				
SO_3	26		15	Bi_2O_3	4		84
$SnCl_4$	26		−33	Parafluorphenol	4	17	28
PbO	25	2	*800	Orthofluorphenol	4	17	16
Ag_2SO_4	24		676	Metafluorphenol	4	17	14
TlCl	24	2	407	HBr	4	2	− 86
KNO_3	24 ×10³	1, 2	345	CH_4	4	1, 2	−184
$FeCl_3$	24	2	01	Metafluoracetanilide	3	17	85
$BiCl_3$	23	2	227				
$SbCl_3$	23	2	73	Difluorethylnitramine	3	17	45
SO_2	23		−76				
$NaNO_3$	22	1, 2	313	Nitrofluorphenetol	3	17	14
$LiNO_3$	22	2	258	Metatrinitrotoluol	3	17	− 2.4
$CdCl_2$	21	2	568	Parafluorphenetol	3	17	− 8.5
Tl_2O	21	2	300	C_2H_6	3	1, 2	−171
SeO_2	21	5	> 260	C_2H_3	3	2	−195
$AlCl_3$	20		190	NH_3	3		− 75
NOCl	− 2	9	− 60	Parafluornitrobenzol	2	17	27
HI	− 3	1, 2	− 51				
H_2Se	− 5		− 64	Ethylenitramine	2	17	6
N_2O_3	− 5	1	−106	SiH_4	2		< 0
Cl_2O	− 6		− 19	Fluornitraniline	1	17	96
CS_2	− 6	1	−110	Dinitrofluorbenzol	1	17	26
N_2O	− 6		−112	Metafluornitrobenzol	1	17	4
AsH_3	− 9		−113				
HCN	−10		− 14	H_2S	1	2	− 86
NO	−11	2	−167	Metacresol	+ .3	17	4
C_2H_2	−12 ×10³	2	− 82	C_7H_8	− .1	2	− 97
C_2N_2	−19	1	− 35	C_2H_4	− .3	2	−169
SbH_3	−22	1	− 91	NO_2	− .6	1	− 10
H_2O	19	1	0	C_6H_6	−1	2	5
$(NH_4)_2SO_4$	19	1, 2	140	Aniline	−1	2	− 8

* = approximate value.

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18. Le Chatelier.

"atomic heats of formation." Here there is no chance for any other factor, such as atomic weight or place in the periodic table, to affect the melting-points consistently. I have not made any selection, but have used all the compounds for which the required data are available. In spite of occasional rather large discrepancies in this table, there can be no doubt that in general the melting-point rises with an increase in the atomic heat of formation.[3]

I have given so much space to this demonstration of the connection between the heat of combination and the melting-point because this seems to be a definite proof that the forces which bind the atoms of different molecules together in the solid state, measured by the melting-point, are similar to those which bind a chemical molecule together, measured by the atomic heat of combination. The similarity must be not only a likeness in nature, but also comparability in magnitude, since if the magnitude of the forces were not comparable there would be no reason to expect the relative melting-points to be comparable with the relative heats of formation.[4] We may consider it established,

[3] Table II and the graph representing it (Fig. 7) are more complete than those given in the original paper. They were shown in their present form before the American Physical Society at its meeting October 30, 1915.

[4] A calculation of the energy required to raise the temperature of a substance from absolute zero to its melting-point and melt it shows that, on the average, this energy is about one-fourth of its heat of formation. Thus the energy required to remove the atoms of a "molecule" in the solid form from the atoms of the neighboring "molecule" is of the same order of magnitude as that required to separate the atoms of the same molecule from each other.

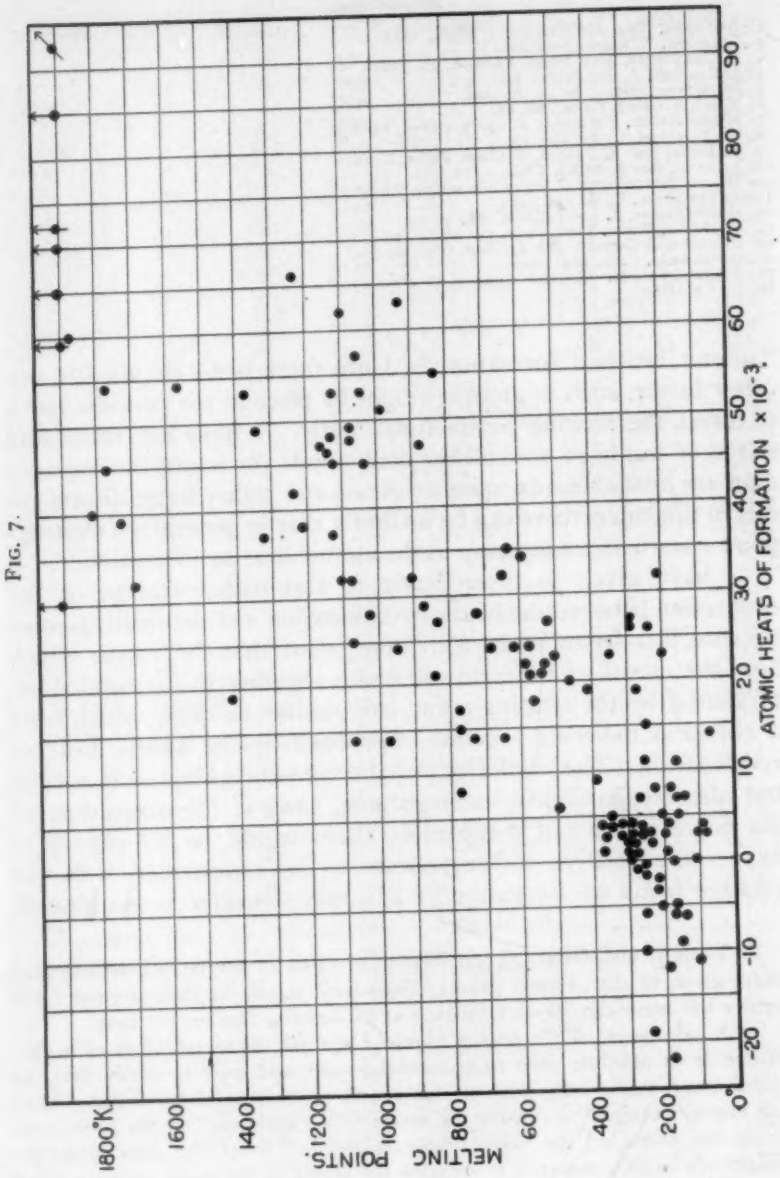

MELTING POINTS.
1800°K.
1600
1400
1200
1000
800
600
400
200
0°
ATOMIC HEATS OF FORMATION × 10⁻³.
90
80
70
60
50
40
30
20
10
0
-10
-20

FIG. 7.

therefore, that in a solid the forces affecting an atom due to neighboring atoms of other molecules are both of the same nature as and comparable in magnitude with the forces due to the other atoms of its own molecule.

It thus appears that the forces of cohesion which hold the molecules in positions of stable equilibrium must be the mutual attractions of the atoms of neighboring molecules. In order, however, that each molecule should be in the most stable position with respect to the other molecules, it is evident that it must orient itself in such a manner that the atoms of different molecules which attract each other most strongly shall be next to each other. One result of this is that the molecules must evidently all be oriented and arranged in a definite, repeating order, which means a crystalline structure. Thus we see that the structure of all true solids must be crystalline. If this is true, the molecules in the so-called "amorphous solids" must not be in positions of most stable equilibrium under the atomic forces, and these substances should therefore have neither a definite melting-point nor perfect elasticity even for small forces. It seems probable that the "near solid state" in which these substances exist is caused by the agglomeration of large numbers of molecules into minute crystalline groups, similar to liquid crystals, which are so large compared with their distances apart that the viscosity is very great.

A second result of this arrangement of the molecules is that since an atom is nearest the other atoms of its own molecule which attract it most strongly, and since it comes next to the atoms of the neighboring molecules which attract it most strongly, it seems probable that, wherever possible, the arrangement of the atoms on all sides of it shall be similar. So if an atom should escape from the other atoms of its own molecule it would be held just as strongly by the atoms of the other neighboring molecules.

The forces on an atom due to the atoms of its own molecule and to those of other molecules, on the average, equal.

The next step in the argument to prove that there is no true molecular structure in the solid state will be to show that the forces between the atoms of the different supposed molecules are as great as those between the atoms of the same molecule. The first part of this proof is to show that the distance between the atoms in a solid is small compared with the "diameters" of the atoms themselves. That is, if the atoms are considered as spheres,

the distance between the surface of two neighboring spheres is small compared to their diameters.

Possibly the most direct way to show this point is to compare the size of the molecules as deduced (1) from the viscosity of a gas, (2) from the thermal conductivity, and (3) from Van der Waals's equation, with the size of the molecules as deduced from the density of the densest known form of the substance, assuming the molecules to be spheres arranged in the order of closest packing. As we saw above, according to the Staigmüller-Boltzmann theory, the atoms of a molecule in the gaseous state are in such close contact that there is no freedom for motion along a chemical bond. So if it can be shown that the molecules are very nearly in contact, the atoms of different molecules must also be very nearly in contact. The following figures are taken from Kaye and Laby's tables, page 33:

Molecular diameter deduced from

	Viscosity	Thermal Conductivity	Van der Waal's Equation	Limiting Density
H_2	2.47 times 10^{-8}	2.40 times 10^{-8}	2.32 times 10^{-8}	2.92 10^{-8}
He	2.18		2.30	4.34
N_2	3.50	3.31	3.53	2.97
O_2	3.39	3.31		2.79
A	3.36		2.86	4.43
Kr			3.14	4.93
Xe			3.42	4.88
C_2H_4	4.55	4.68		5.26
CO_2	4.18	4.32	3.40	4.42
N_2O	4.27	4.20		4.58
H_2O	4.09			3.49

These data assume that the molecules are spherical, which undoubtedly introduces some error, but the uniformly close agreement of the values in the fourth column with those in the other three can leave but little doubt that the molecules in the solid state, and hence the atoms also, must be very nearly in " contact."

In support of this evidence for the proximity of the atoms in a solid we may mention the evidence which comes from the X-ray spectra from different crystals that the distance of the thermal motion is small compared with the diameter of the atoms themselves. This evidence comes from a consideration of the relative intensity of the different orders of spectra. At first the rapid falling off in intensity of the higher orders for such crystals as

rock salt when compared with crystals like potassium ferrocyanide was explained as due to the greater heat motion of the lighter atoms in the former case. But the Laue photographs which de Broglie obtained at great extremes of temperature—from liquid air to red heat—showed a surprisingly small difference in the intensity of the spots, showing that the heat motion has very little effect. Apparently the only remaining explanation is that the X-rays are not reflected from single points in the atoms, but by electrons distributed throughout the atoms. Thus it is the size of the atom compared to the distance apart of the reflecting atoms which accounts for the decrease in intensity of the higher orders of spectra. (If a large proportion of the electrons are in the central ring about the nucleus, the intensity should not diminish as rapidly as if they are uniformly distributed throughout the sphere. It should be possible to test this point.[5]) But since the heat motion of the atom does not materially affect the intensity of the higher orders of spectra, while the diameter of the atoms does so affect it, the distance of the heat motion, and hence the distance between the atoms, must be small compared with the diameter of the atoms.

A more definite confirmation comes from the arrangement of the atoms in those simple crystals whose structure has been worked out. If we assume here the existence of molecules, the distance between the atoms within a molecule is the same as that between neighboring atoms of different molecules. The atoms of the same molecule are certainly very near together, however, so for these simple compounds, at least, any two neighboring atoms are very close together.

One further line of evidence toward this same point may be valuable. The expansion of solids on heating is due, of course, to the lengthening of the paths of the molecules as the temperature

[5] It was this fact that suggested the writer's study of the distribution of the electrons in atoms as indicated by the intensity of X-ray reflection (cf. *Nature*, May 27, 1915, and *Phys. Rev.*, 9, 29, 1917). In the latter paper it was shown that the distance of the outer electrons from the atomic centres was comparable with the distance between the atoms. According to Debye's theory of the effect of heating on the intensity of X-ray spectra (*Ann. d. Phys.*, 43, 49, 1914), which has been verified experimentally by Professor Bragg (*Phil. Mag.*, 27, 881, 1914), the thermal motion is relatively small, and reduces to practically zero at very low temperatures, as is here suggested.

rises. It seems natural to suppose that at absolute zero the length of these paths would decrease until the molecules come in contact. Even if the coefficient of expansion were constant the volume of a solid would not decrease enough to indicate at ordinary temperatures a free path comparable with the diameter of the atoms. As a matter of fact, at low temperatures the coefficient of expansion approaches zero, which indicates an "agglomeration" into groups in which the atoms are all in contact. This is the same theory of agglomeration as the one used to explain the decrease of specific heat at low temperatures. If this theory is correct, at low temperatures all the atoms, whether of the same or of neighboring molecules, are held in "contact" with each other.[6] We may conclude, then, with considerable certainty that the atoms of neighboring molecules are very nearly in contact with each other, and that they are probably as near together as the atoms of the same molecules.

We showed above that the forces between atoms are of the same nature, whether due to atoms of the same molecule or to those of different molecules. It seems evident, therefore, that the attraction between atoms should be some function of the distance such that if the distances are equal the forces should also be equal. This is confirmed by the evidence of chemical action which we considered above. But, since we know that the distances between atoms of the same molecule and atoms of neighboring molecules are approximately equal, the forces should likewise be very nearly equal. Thus we see that the forces on all sides of an atom must, on the average, be at least very nearly the same.[5]

We can go still farther and show it to be probable that the forces on an atom due to the atoms of neighboring molecules are, on the average, exactly equal to the forces from the other atoms of its own molecule. From the discussion in the last paragraph we see that an atom is as strongly attracted to another atom with which it is in contact, though of a different molecule, as it is to a similar atom in its own molecule. When, therefore, due to the heat motion of a molecule in the solid, one of its atoms comes in contact with an unlike atom of a different molecule, there are even chances that it will remain fast to the other molecule. So

[5] The theory referred to is that suggested by C. Benedicks (*Ann. d. Phys.*, **42**, 133, 1913).

in a very large number of collisions it will belong just as much of the time to one molecule as it will to the other, and so cannot be said to be a part of either. As a matter of fact, since we know, from a study of the Dulong-Petit law, that an atom has three degrees of freedom in a solid, and since an atom cannot remain joined to another without losing a degree of freedom (Staigmüller-Boltzmann Theorie), it is evident that an atom cannot remain in contact for more than an infinitesimal interval with another atom, but must continually oscillate back and forth, exerting equal attractions on all the neighboring atoms.

The fact that Dulong and Petit's law is not accurately followed—*i,e.*, that the atoms of solids do not always have three degrees of freedom, is a support rather than an objection to our hypothesis; for as the temperature decreases, the time interval during which an atom remains in contact with a neighboring atom will, on the average, increase, thereby decreasing the total number of degrees of freedom at any one instant. In the gaseous state, as we have just seen, each atom has three degrees of freedom minus the number of its chemical bonds. But if the gas is heated to a sufficiently high temperature it becomes ionized; that is, the chemical bonds become loosened so that parts of the molecule occasionally separate (Meyer, "Kinetic Theory of Gases," p. 132). According to our hypothesis, when a molecule assumes the solid state, the attractions of the neighboring atoms loosen the chemical bonds sufficiently to give each atom three degrees of freedom. Even in the solid state, however, each atom is strongly bound to the neighboring atoms, so that if the kinetic energy of the atom should become sufficiently low, one would expect it to be held in contact with some of the other atoms thus taking away its degrees of freedom, until it should be moved from its place by a sufficiently violent collision. This would be exactly analogous to the binding of the atoms together in a gas molecule until there is a sufficiently violent collision to ionize the gas. The only differences are that, since the atom in the solid state is not held so strongly by other atoms, the collisions would not have to be so violent, and that, since the atom in the solid state is surrounded by other atoms, it might have either zero, one or two degrees of freedom when held in contact with other atoms. It is easy to see that on this hypothesis, when the kinetic energy becomes sufficiently low, large numbers of the atoms will

be held in contact with each other, thus losing their degrees of freedom, so that as absolute zero is approached the specific heat should also approach zero. This is, I believe, about the same as the "Agglomeration Theorie" on which Dean Magie reported to Physics Colloquium last winter.[7]

CONCLUSION.

THE STRUCTURE OF SOLIDS IS NOT MOLECULAR.

Since, therefore, each atom of a substance in the solid state exerts equal forces on all the neighboring atoms, it cannot be said definitely to belong or not to belong to the same molecule as some other one atom.[8] In other words, the atoms of a solid are so intimately intermingled that particular molecules cannot be definitely defined. Thus we can no longer speak of solid

[7] These were the considerations which led to the development of the theory of specific heat presented by the writer in the *Physical Review*, 6, 377, 1915, where it was found that this agglomeration hypothesis is capable of explaining in a fairly satisfactory manner the variation of the specific heat of solids with temperature. It may be pointed out that the theories of the temperature variation of specific heat based on the quantum hypothesis (Einstein, Nernst-Lindemann, Debye) lead to the same conclusion as that here arrived at concerning the rigidity with which atoms are held in a solid. According to these theories, the energy corresponding to a degree of freedom depends upon the corresponding frequency of vibration. In the case of gases this frequency is very high, while in the solid state the frequency of the natural vibrations of the atom is relatively low. This means that the rigidity with which the atom is held in position is much less in the solid state than in the gaseous state, due doubtless to the fact that the forces due to the surrounding atoms are nearly equal on all sides.

[8] On account of the selective nature of the forces between atoms, we can state these forces as a function of the distance only when we consider but a single arrangement of the atoms. This argument therefore proves that the "bonds" on the different sides of an atom are of the same strength only for those atoms which have similar atomic groups arranged symmetrically about them. For this reason it is probable that there are some complicated compounds in which certain groups of atoms may retain their identity in the solid state. The writer has been unable to think of any substance, however, which could crystallize in such a manner that some one atom would not be equally strongly bound to two or more similar atomic groups. The molecule is therefore indeterminate, inasmuch as this particular atom cannot be said to belong to one atomic group rather than to another.

matter as having a molecular structure, but must consider it to be purely atomic, which is the thesis we started to prove.[9]

A CONSIDERATION OF OBJECTIONS.

As an immediate result of our hypothesis it must follow that matter in the solid state can have no properties which depend upon a molecular structure as distinguished from an atomic structure. It is important, therefore, to consider those explanations of properties of solid matter which involve a molecular structure. All

FIG. 8.

such explanations which I have been able to find are those which consider solid matter to be made up of electric or magnetic doublets. For instance, there is the common explanation of electric strain as due to molecules in the dielectric which are made up

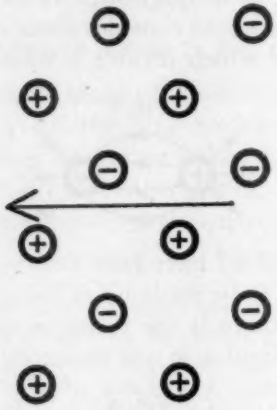
FIG. 9.

each of two portions, one positively, the other negatively electrified, and that the two portions are shifted by the forces accompanying the strain. Of course, in making this assumption chemical and electric attraction are identified, as we have assumed

[9] Langmuir's conclusion from similar considerations is rather that the crystal is a single molecule. The difference depends chiefly upon whether the molecule is defined as the smallest portion of a substance which has the characteristics of the substance or as a group of atoms held together by chemical forces. The above argument is based on the former definition, contending that these smallest portions cannot be definitely defined. Langmuir concludes, on the basis of the latter definition, that, since all the atoms in a crystal are similarly bound together, the whole crystal is a single molecule. Since, however, the forces of cohesion and adhesion are essentially identical with chemical forces, a similar argument would show that the whole earth, and perhaps even the whole universe, is a single molecule. The writer therefore prefers the former conception of the molecule as having a more definite meaning.

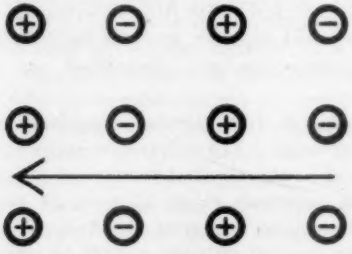
above. Following Poynting and Thomson ("Electricity and Magnetism," p. 59): "We may, for our present purpose, . . . conventionally represent a molecule as in the figure (Fig. 8) . . . If the dielectric is in a neutral condition, we must suppose that the molecular axes are distributed equally in all directions, . . . and

FIG. 10.



there is no resultant electric action outside." When an electric field is imposed, these molecules arrange themselves as in Fig. 9, which has the same effect as placing a charge on the surfaces of the dielectric.

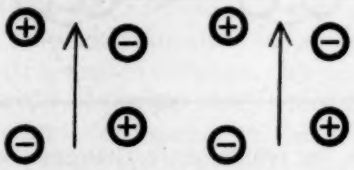
FIG. 11.



If this means that the molecules are capable of rotation through any angle, then in a crystal such as a KCl crystal, if the electric field were perpendicular to the (111) planes, as in Fig. 10, the supposed molecules would arrange themselves as in Fig. 11. Thus the (111) planes would become cleavage planes, which is evidently absurd, since there is no apparent change in the crystal

structure. But if the theory means only that a molecule can be turned slightly from its stable position, there is nothing which requires a true molecular structure, since a slight shift in the position of the atoms will produce the same result. (If this shift in position is great enough, it should be possible to detect it in crystal dielectrics by obtaining X-ray spectra from them. For example, if the electric field is perpendicular to a cleavage plane of a KCl crystal, we might expect the atoms to be displaced as in Fig. 12. It may be shown that such a displacement would reduce the comparative intensity of the higher orders of

FIG. 12.



spectra, and this, by careful measurement, might be noticeable.)

Another explanation of electric phenomena which apparently depends upon a true molecular structure in a crystal is Lord Kelvin's explanation of pyroelectricity, which is also extended to piezoelectricity. As explained in Poynting and Thomson ("Electricity and Magnetism," p. 150), this explanation is: "The molecules are set in the crystal with their electric axis

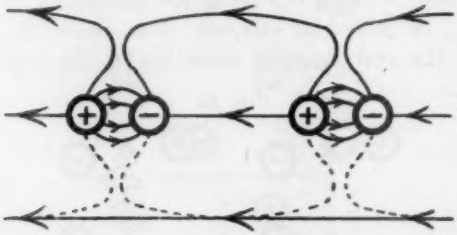
FIG. 13.

parallel to a certain direction, and there will therefore be a definite amount of strain passing from each positive element of a doublet to the negative element of the doublet next to it. The crystal, as a whole, will be the seat of an electric strain along the direction of the axis. The constitution corresponds to that of a saturated permanent magnet on the molecular theory of magnetism. The electric strain will manifest itself almost entirely at the ends of the crystal if the doublets are near enough together, and the crystal will produce a field outside equal to that which would be produced by charges respectively positive and negative at the two ends. . . . But . . . charges will in time gather on

the surfaces at the ends of the axis, . . . entirely masking the existence of the strain, so that there is no external field. This is the ordinary condition of a neutral crystal.

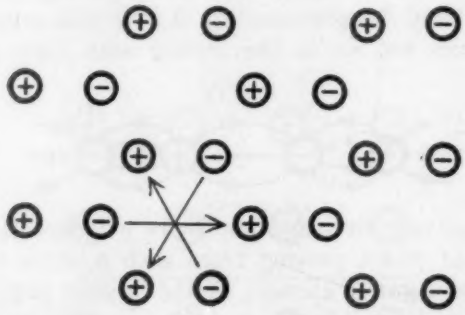
"We have now to suppose that the electric strain passing forward from molecule to molecule depends on the temperature, and that it alters nearly in proportion to the change in tempera-

FIG. 14.



ture. Then when the temperature changes there will be an unbalanced strain proportional to the change, producing the same effect as a positive charge at one end and a negative charge at the other until conduction again does its work in bringing up masking charges."

FIG. 15.



The mechanical model which Poynting and Thomson suggest as an illustration is a series of molecular doublets, arranged as illustrated in Fig. 13, which, when heated, assume the arrangement shown in Fig. 14 as the molecules become separated. Here certain of the lines of force combine, giving the effect of a free charge at either end. This model would explain pyroelectricity as due merely to molecular separations, and we ought to get a

similar effect if the molecular separation is produced by tension, which is the piezoelectricity found by Curie.

An objection to this model is that it assumes that as the temperature rises the parts of the molecule come relatively closer together, while experiments in specific heat seem to indicate that with rising temperature the parts of a molecule become farther separated. A model to which this objection does not apply, which does not assume any molecular structure, and which accords fully with Kelvin's explanation, may easily be imagined. Suppose the atoms in a crystal to be arranged as in Fig. 15. It will be seen at once that such an arrangement will correspond to the "saturated permanent magnet on the molecular theory of magnetism." The left end will have the equivalent of a positive charge and the right end that of a negative charge. There will evidently be in this model three different axes along which there will be such an effect, which might correspond to the three electric axes of a quartz crystal. As the atoms move farther apart with a rise in temperature the strength of the doublets is increased, and, if the ends were neutralized before, a new charge will now appear.

Of course, the same result would occur here also if the atoms were separated by tension, which would explain piezoelectricity. If the structure of a quartz crystal can be determined as the Braggs are now trying to do, it will be an easy matter to see whether a true molecular structure is required for the explanation of pyro- and piezo-electricity.

There are, however, some difficulties with a complete explanation of the magnetic properties of solids, without assuming a molecular structure, that are not so easily met. One of the arguments for a molecular structure from magnetic properties comes from a consideration of the Heusler alloys. In these alloys no element by itself is very strongly dia- or para-magnetic, but when the different elements are alloyed the mixture is almost as paramagnetic as iron. From this it might be concluded that atoms from two different slightly magnetic substances can combine to form a molecule that is ferromagnetic.

We have, however, strong indications that magnetism is a purely atomic property. A good experimental indication of this comes from depositing iron electrolytically in a magnetic field. For instance, if a varnished silver wire with a thin scratch through the varnish is placed in a solution of ferric chloride, when the

iron is deposited electrolytically an extremely small magnetic field will make of the deposited iron a saturated magnet. This indicates that the elementary magnetic doublets are easily turned around while the iron is being deposited. The iron is deposited, however, atom by atom, and, since the position taken by each atom is determined by the crystal form and not by the magnetic field, it must be the atoms and not the molecules which are oriented by the magnetic field.

Perhaps the strongest evidence that the magnetic effects are not molecular but atomic phenomena is the fact that the structure of the atom which the most generally accepted theories suggest offers an excellent explanation of magnetism as due to atomic properties. I refer to the theory that the atom consists of electrons revolving in orbits, held together by the appropriate positive charge. This, of course, makes each atom an elementary magnetic doublet. Langevin and Weiss have developed a complete theory on this assumption (Professor Richardson's lectures on "Electron Theory"), explaining both dia- and para-magnetism, which seems to be as satisfactory as any yet proposed. The fact that a theory based on this assumption explains magnetic phenomena so well without any reference to a molecular structure would indicate that these effects have no dependence on molecular structure.

However, we have good reason to believe that the environment of an atom greatly influences its magnetic properties. For instance, different samples of iron vary greatly in their magnetic properties, according to their temper, per cent. of carbon, amount of alloy, temperature, etc. The explanation of Heusler alloys would therefore seem to be that the environment of the atoms of the different elements is changed in such a manner by being alloyed that they are free to turn under a magnetic field.

There is another difficulty, however, which results from a purely atomic explanation of magnetism. This is an explanation of the heating effect when a piece of iron is placed in an alternating magnetic field. This alternating magnetic field, if intense enough, is supposed to turn the elementary doublets completely around. If these doublets are molecular, it is easy to see how their turning can impart kinetic energy to the system and so raise the temperature; but if they are atomic, since only the translational degrees of freedom of an atom are supposed to

possess heat motion, any amount of rotation of the atom would not affect the temperature of the substance. Two possible explanations may be offered. In the first place, it is possible that, since an atom can no longer be considered to be a sphere, its rotary degrees of freedom actually do enter into the thermal motions. Or, in the second place, though the rotary degrees of freedom may not themselves enter into the heat motion, it is possible, since the atoms are not spheres, that their rotation may displace other atoms translationally, which would account for the heating effect. It must be confessed, however, that neither of these explanations appears wholly satisfactory, and that this heating effect presents a real difficulty to any non-molecular explanation of magnetic phenomena.

A test for this point would be to take Laue photographs through a crystal such as pyrrhotite, which shows magnetic effects, and see if there is any change in the internal structure when the crystal becomes saturated.[10]

SUMMARY.

To sum up our argument then: It is shown, in the first place, that the arrangement of the atoms in certain crystals, as determined by their X-ray spectra, indicates definitely that in these crystals there is no molecular structure.

In extending the argument to all solid matter it is pointed out, from the dependence of crystal form on chemical composition, from a consideration of the Dulong-Petit law and of the nature of cohesion, and from the evidence of X-rays as to certain crystals, that each atom in a solid oscillates about a definite position of stable equilibrium.

From a further examination of the nature of cohesion and of the forces concerned in chemical combination and especially from the general relation found between the atomic heat of formation of a substance and its melting-point it is found that the forces

[10] This test was suggested by my brother, K. T. Compton. It has been made by K. T. Compton and E. A. Trousdale (*Phys. Rev.*, **5**, 315, 1915) and repeated with greater care by the writer and Oswald Rognley (*Science*, N. S., 46, 415, 1917). These experiments show that when magnetic crystals are saturated magnetically the atoms are not displaced by as much as 1/250 of the distance between the atoms. Magnetic effects are therefore not due to rotations of the molecules, but must be due to the atoms or something within the atoms.

holding the atoms in their positions of stable equilibrium are of the same nature and comparable in magnitude with the forces binding together a chemical molecule.

It is seen further that the atoms in a solid are very close together, so that they often come in contact. And, since an atom attracts equally all atoms of another kind which are in contact with it, an atom cannot remain combined for more than an infinitesimal interval with any other particular atom at ordinary temperatures.

Finally, it was shown that, since in the solid state each atom has three degrees of translational freedom and is strongly attracted by atoms other than those of its own "molecule," it must, on the average, exert equal attractions on all the neighboring atoms.

From this the conclusion is drawn that in the solid state the atoms are so intimately intermingled that particular molecules cannot be definitely defined.

When those properties of solid matter which have been explained by molecules are considered, nothing is found which indicates at all definitely a molecular structure.

We feel justified in concluding, therefore, *that the structure of solid matter is not molecular.*

July 25, 1914.

Largest High-head Francis Turbine. ANON. (*Electrical Review*, vol. 72, No. 10, p. 417, March 9, 1918.)—The Puget Sound Traction, Light and Power Company, of Seattle, Wash., is installing a new turbine unit of 25,000 horsepower capacity in its White River hydro-electric plant in the vicinity of Sumner, Wash. The two original units, which were installed in 1911, have a rated capacity of 36,000 horsepower, but in actual practice have carried a load of 44,000 horsepower. This equipment, which includes Francis turbines, was built by the Allis-Chalmers Manufacturing Company, the plant having been designed and installed under the supervision of Stone & Webster, engineers. The new installation is being made primarily to supply the power required by the Chicago, Milwaukee and St. Paul Railway Company to operate passenger and freight trains over the Cascade Mountain division in Washington.

The new unit being installed consists of equipment similar to that of the two units now in use; the new Francis turbine, however, having a capacity of 25,000 horsepower, is the largest of this type ever built. The turbines of the two original units are of the double-discharge horizontal type with spiral case, operating at 360 revolutions per minute under a head of 440 feet. These turbines have shown very high efficiency under test.

THE EFFICIENCY OF LIGHT-PRODUCTION IN ORGANISMS.*

BY

ENOCH KARRER, Ph.D.,

Physicist, Research Department, United Gas Improvement Company.
Member of the Institute.

THE production of light by organisms has always been a subject of much comment by men who are interested in the economics and mechanism of light-production.

It is therefore well to consider what the efficiency of this process may be, judging, as we must, from what the efficiencies are, in general, of energy transformations in the organic world. It is frequently stated that the efficiency of light-production by the firefly is very high—inferred without foundation from the fact that the energy radiated by it is highly concentrated in a band in the visible spectrum; or from this in conjunction with the fact that an insect possesses relatively very great strength.

The luminous efficiency of the radiation from the firefly is 97 per cent. This efficiency, however, is merely one element in the whole process of light-production. There are several processes whose efficiency must be reckoned also, and which may tell us more concerning the light-source than this.

A few general considerations will make this clear.

Let $e_{l.r.}$ represent the luminous efficiency of the radiation. Then by definition we have $e_{l.r.} = \frac{L}{R}$; where R is the energy radiated at all wave-lengths, both visible and invisible, and L is the energy radiated in the visible portions of the spectrum after being reduced at each wave-length to some arbitrary unit of luminosity,

$$\text{or } L = KV$$

$$\text{and } R = V + r = \frac{L}{K} + r$$

where K is the mean value of the visibility,[1] V is the radiant power in the visible portion of the spectrum, and r is the radiant power in the non-visible parts of the spectrum.

$$\text{Then } e_{l.r.} = \frac{L}{\frac{L}{K} + r} = \frac{1}{\frac{1}{K} + \frac{r}{L}} = \frac{K}{1 + \frac{r}{V}}$$

* Communicated by the Author.

Now $K \gtreqless 1$, if we choose as the unit of visibility that at wave-length of maximum visibility (0.555μ).

According to this equation, $e_{1.r.}$ may have values from 0 to 1 when $K = 1$, and from 0 to K when $K < 1$. When $K = 1$, all the energy of the spectrum lies at wave-length of maximum visibility. In order that $e_{1.r.}$ may be large, say greater than 50 per cent., the amount of energy in the infra-red must be less than that in the visible region.

These considerations hold generally for common light-sources and for luminescence produced by other means. However, there may arise some unusual property of the light-source or some unusual conditions under which the measurements are made that will render the value of $e_{1.r.}$ much more difficult of interpretation.

As examples of such cases may be instanced the luminescence produced in a chemical reaction which is endothermic. If we imagine determinations of $e_{1.r.}$ made by means of a radiometer (a thermopile and galvanometer) we will obtain a certain deflection (say positive) when the visible portion only is considered by interposing a "luminosity screen" between the light-source and the sensitive surface of the radiometer; while the deflection we obtain as a measure of the total energy radiated may even be negative, if the reaction were sufficiently endothermic to allow the light-source to absorb more energy from the thermopile than it radiates upon it. Logically, then, we have for our defining

$$\text{equation } e_{1.r.} = \frac{1}{\frac{1}{K} - \frac{r}{L}} = \frac{K}{1 - \frac{r}{V}}$$

Under the conditions postulated $e_{1.r.}$ may have any value between $+\infty$ and $-\infty$.

An instance[2] of an endothermic reaction producing luminescence is that of iodide of Mellon's base. It has never been determined whether the reaction producing the light in organisms is endothermic or exothermic.

Conditions postulated above wherein negative values of $e_{1.r.}$ are obtained may be realized in a manner other than by endothermic reactions giving light. The luminescence given by bodies when kept at liquid air temperature would show ostensibly the same effects.

No data are available from which the efficiency of any energy

transformations in insects may be approximated. However, the efficiency of energy transformations in the insect is probably of the same magnitude as that in case of higher animals about which more data are at hand.

The popular conception that the insect is very much more efficient in transforming food energy into mechanical energy than a mammal is based upon the idea of the " strength " of the insect. For example, an ant can carry many times more its own weight than an elephant, and a grasshopper can leap many more times its own length than a kangaroo. In all such instances, however, we are not taking account of the total energy involved, but are referring to the speed of utilization of energy of a stored substance. In the cases cited there is probably normally involved only the speed of oxidation of glucose in the muscle-cells; while the production, transportation, and storage of the glucose or glycogen is not involved at the moment the extraordinary movements are made.

In support of the assumption that the efficiency of the physical and chemical processes maintaining in organisms does not vary widely from the insecta to the mammalia may be noted some comparative data pertaining to the process of respiration.[3]

In the following table is given the ratio between the oxygen expired as carbon dioxide and the oxygen inspired as air for various creatures:

Bee	0.81	Rabbit	0.92
Fly	1.14	Dog	0.74
Sparrow	0.79	Horse	0.91
Hen	0.90	Man	0.78
Mouse	0.80	Lizard	0.75
Guinea Pig	0.86	Frog	0.80
Carp	0.66	Starfish	0.78
Octopus	0.86		

This ratio is very sensitive to temperature changes,[4, 5] and large discrepancies that exist can probably be accounted for.

In a general way there is the efficiency of each of two steps in the energy transformation in organisms to be considered: First, the efficiency of food intake and of its transformation into the final product, and of storing the final product for subsequent use; second, the efficiency of taking from storage and utilizing the final substance for the production of muscular and other forms of energy.

If we designate the numbers representing these efficiencies by e_p and e_u respectively, then the total efficiency is $e_p \times e_u$. The efficiency of production of the final substance and the efficiency of utilization of the substance in the firefly are unknown, as in all cases of light-production by organisms. The corresponding values for the transformation of the energy in gas and in the electric current into mechanical energy are as follows:

For gas e_p is 66.5 per cent.—made of two factors of producing and storing the gas, 70 per cent., and for distributing the gas to the motor, 95 per cent. The efficiency, e_u, of the gas motor may be 25 per cent. The efficiency of the whole process is $e_u \times e_p =$ 16.6 per cent.

Similarly for the electric current we have $e_p = 11.9$ per cent. roughly—made of the two factors of producing the electric current and bringing to the buss-bars, 13 per cent., and for distributing to the motor, 92 per cent. The efficiency of the electric motor may be taken as 95 per cent. So that the efficiency of the whole process becomes $e_p \times e_u = 11.3$ per cent.

When we come to consider the transformation of the energy into light there enter the efficiencies of still further steps relating to the radiation of the energy. We may very conveniently now look upon e_u as made up of two parts: First, the total amount of energy radiated with reference to the total available energy; second, the amount and quality of this radiated energy lying in the visible region of the spectrum.

The latter is the lighting or luminous efficiency of the radiation. In case of the firefly this is 97 per cent.—exceedingly high compared with that of ordinary light-sources. The luminous efficiency of the radiation from a Welsbach mantle lamp is 0.476 per cent., and of that from the tungsten filament lamp is 1.65 per cent., while that of the yellow flame arc is 13 per cent.

The former is the radiating or radiational efficiency. This, in case of the firefly, as in all organisms producing light, is unknown. For the Welsbach lamp it is 25 per cent., for the tungsten lamp 90 per cent. Sources of losses that will make the radiating efficiency low may be either physical or chemical.

The efficiency of the production of light by an organism, reckoned from the time the light-giving substance begins to react, is given by $e_{l.r.} \times e_r$; where $e_{l.r}$ has been previously defined, and $e_{r.}$ is the radiating efficiency.

The efficiency of the whole process of light-production is given by $e_l = e_p \times e_r \times e_{l.r.}$ The value of this product is not known for many light-sources other than the ordinary gas and electric lamps.

For the Welsbach gas lamp the value of e_l is 0.08 per cent., and for the tungsten electric lamp it is 0.13 per cent.; where the constituent parts of e_l are as follows:

	e_p	e_r	$e_{l.r.}$	e_l
Electric	0.09	0.90	0.0165	0.0013
Gas	0.67	0.25	0.0048	0.0008

Any single one of the factors tells us little, as we have seen above. The numbers given in the table are merely intended to give an idea of the magnitudes that may be or are attained. In practice they vary considerably, depending upon the size of the gas or electric plant.

In the product of these factors e_p is not known for the firefly. However, an idea may be gotten of a permissible magnitude of it from a consideration of the magnitude of the efficiency of other processes carried on by organisms. This is the chief purpose of this paper.

There has been some excellent work done upon the strength of insects, but it is to be regretted that in most cases the results are only qualitative or the necessary data have not been recorded. As an instance of the strength of insects may be cited that of a large beetle (*Passalus cornutus Fob.*). This beetle is 1.1 cm. across and 3.3 cm. long, and weighs 1.04 g. The following numbers are the ratios of the weight of the load to the weight of the insect and express the strength of the insect in various attitudes:

Horizontal pull upon wood	19.66
Horizontal pull into furrow	158.73
Vertical pull	10.0
Lifting strength by head:	
(*A*) By promesothoracic muscle alone	35.4
(*B*) By aid of forelegs, too	122.8

The beetle crawled with a weight of 700 g. upon its back.

During the time of working the beetles lost 2.89 per cent. of their weight, as compared with 0.62 per cent. in control beetles.

The author concludes that there is no relation between the

loss in weight to the work done. It is to be regretted, however, that he fails to record the amount of work done.

These data are the nearest approach to what is necessary in order to calculate the efficiency of transformation by an insect of the chemical energy in a stored substance (probably glycogen) into mechanical energy. This would give e_u as defined above.

Some partial data, but insufficient, for the common housefly [9] (*Muscæ domesticus*) and for the boll-weevil [10] may be found.

For data regarding the transformation of the energy of the food into energy other than mechanical, one would naturally look to the cow among the higher animals and to the bee and silkworm among the insects. In each of these cases the chemical energy in one substance is transformed into chemical energy in another substance—the energy of the grain into chemical energy of the milk; the energy of the pollen and sugar into that of wax; the energy of the mulberry leaf into the energy of the silk.

With these instances of energy transformation of such tremendous importance to mankind it is surprising to find such a meagreness of data regarding them.

In an experiment [11] with bees it has been found that 12 g. of cane-sugar produced 1 g. of wax. The amount of fats and nitrogen compounds experienced no change during the progress of the experiment, so that we have here an excellent example of transformation of chemical energy in food to that in a secreted substance.

The energy content of sugar is 1860 cal./g. The energy content of the wax is more uncertain. The heat of combustion of unrefined beeswax is 16492 B.t.u. per lb. (9043 cal./g.). Here the efficiency of the energy transformation is 40.5 per cent.

In another experiment [12] 1250 g. of honey, together with 117 g. of pollen, made 84 g. of wax. When the bees were fed 1250 g. of honey alone only 51 g. of wax was produced. Let us assume, then that 117 g. of pollen produced 33 g. of wax.

The heat of combustion of pollen varies probably, and it is not known what pollen was used in the experiment.

The heat of combustion of ragweed pollen * as recently de-

* The ragweed pollen was kindly supplied by the Upjohn Chemical Company, Kalamazoo, Mich.

termined is 8776 B.t.u./lb. The heat of combustion of beeswax is 16492 B.t.u./lb. Therefore for this transformation we have the efficiency equal to 5.3 per cent.

Honey is not a true secretion, but the nectar of plants after having been acted upon by some of the secretions of the bee. This fact should be manifested by an extremely high efficiency.

The insect world offers us another prominent example in the silk-moth whose larva produces the silk. Silk is a true secretion and is formed from the mulberry leaves devoured by the silkworm.

We have some data [13] available relating to the production of silk by the silkworm for a given quantity of leaves consumed, but the data lacking for our calculation are the heat of combustion of mulberry leaves and that of the silk.

It has been estimated [14] that about 18 per cent. of the energy of the feed is transformed into energy of the milk by the cow. While about 24 per cent. of the energy of the grain is transformed and stored in pork, only 3.5 per cent. is stored in beef and mutton.

These figures are e_p, defined above, for these organisms. Even if e_u be very high, the product of the two will be low. Of the magnitude of this product we may judge by comparison with results of the determinations of the mechanical efficiency of the horse and of man. In the former [18] the net efficiency is often above 30 per cent. In the latter [19] it may also be nearly as high under the best conditions of speed and coördination; while for slow-speed performances and under ordinary conditions it is very much lower.

The last figures are for the net efficiency; the gross efficiency is considerably lower. For example, the gross efficiency for a man riding a bicycle is 16.1 per cent.,[20] while the net efficiency is 24.9 per cent.

The net efficiency is derived by deducting from the total energy input the energy that is necessary to keep the organism in a normal condition, or in a zero position as regards the performance under question.[20]

We may infer, then that if the product of e_u and e_p for the firefly is 20 per cent., it is a probable value, though perhaps a high net value as the efficiency of energy transformations in the organic world run.

The efficiency of the light-production by the firefly, then, is 19.4 per cent.

We are assuming that e_r is 100 per cent.; *i.e.*, that there are no losses by conduction and convection, or by the formation of chemical compounds, when the reaction producing the light takes place.

The "mechanical equivalent" of light is 49.1 candles per watt.[21, 22] We have an efficiency expressed in ordinary units of 0.1 watt per candle.

From a consideration of the relative size of the firefly and the proportion of tissues producing the light it has been estimated that the efficiency is 0.054 watt per candle.[23]

The energy of the light from all sources considered comes from the sun. Let us consider the species of firefly that is herbiverous. The plant stores as chemical energy between one and two per cent. of the energy of the sun falling upon its leaves.[24] If we also consider that much of the sun's energy is lost in the earth's atmosphere,[24] we find that about 0.19 per cent. of the original solar energy is given back as light by the firefly. By the use of coal and gas or electric lamps the fractional part of the original solar energy that is obtained as light again is of the order of 0.0007 per cent. This figure is certainly too large, for no allowance for the waste of coal by erosion was made, nor was the whole of the earth's surface considered.

All the figures which have been given above hold only for the lapse of time of our experiment and become appreciably less when longer intervals are considered—the hours of activity as well as the hours of rest, the night as well as day, and all seasons and ages.

The most important sources of information regarding the subject-matter discussed above are given in the bibliography below, some of which have not been directly referred to in the text.

I am indebted to Mr. W. H. Fulweiler for the determination of the heating value of beeswax and pollen. I wish also to express my appreciation to friends in many departments of science whose suggestions and attention have been invaluable.

PHYSICAL LABORATORY,
The United Gas Improvement Co.,
February 23, 1918.

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Rail-creep. F. REEVES. (Proceedings, Institution of Civil Engineers through *Scientific American Supplement*, vol. 85, No. 2202, March 16, 1918.)—Rail-creep has been commonly believed to be caused mainly by temperature changes, assisted by the movement of trains. Experiments made several years ago by the author indicate that the primary cause is the deformation of the rails under the rolling loads, assisted by temperature changes, which cause fish-joints to slip and lessen the resistance. The first experiments consisted in passing a wooden wheel several times in succession, in one direction, over a planed white-pine lath resting on a hardwood bench.

The lath was found to have moved bodily about two millimetres in the direction of travel, the total amount of the latter having been about fourteen metres. Further experiments were made not only with pine laths but also with flat iron bars on side and on edge, and with a strip of India rubber. The conclusion drawn from these experiments is that creep is due primarily to deformation of the rail as the wheel passes over it. With the pine lath the creep was always from twice to four times the amount when the lath was supported on sleepers. The effect was heightened when the lath was on the flat as compared with the same lath on edge.

Where track is on a yielding roadbed, creep is intensified, especially under heavy wheel loads. It is also accentuated by braking in places where regular stops are made. On single lines there is normally no trouble with creep, but if there is any great preponderance of traffic in one direction, more or less creep takes place in that direction. It is easy to reduce creep to a small amount by putting in anchors, but is is not easy to suppress it entirely on double lines under modern conditions. In double track the outer rails (the rails near the edge of the ballast) move more than the inner. There would be little harm in creep if all the track were "open track" and both rails "ran" equally. Where it compels preventive measures is at connections with other lines, junctions, sidings, crossovers, etc. The only practical way to anchor track is over long stretches and through numerous sleepers.

Dam Sites on the Missouri River in South Dakota. D. ROBINSON. (South Dakota Department of Immigration, January, 1918.)—The extent of the undeveloped water powers in the United States and the limitations to their utilization have long been appreciated by hydraulic engineers and economists, but the stress of war-time conditions resulting in an extraordinary fuel shortage has brought the subject prominently into view and aroused a widespread appreciation of the importance of utilizing available sources of water power. A study of possible dam sites for power projects along the Missouri River within the boundaries of South Dakota is a notable example of an increasing interest in the subject.

South Dakota is peculiarly fortunate in the natural formation of the Missouri River valley which makes it possible to construct a considerable number of water powers upon that stream. This is a resource peculiar to South Dakota, when at frequent intervals the river-walls of the immediate valley of the stream approach each other so closely as to make the erection of dams feasible. The minimum discharge of the Missouri in the northern part of South Dakota is 10,000 second-feet. It rarely, if ever, reaches this minimum. The average discharge is 24,833 second-feet for the entire year, and the average for the growing season is 37,500 second-feet. The combined minimum effected power developable at seven sites suggested is 242.000 horsepower. The average flow of the stream will produce at the same heads 552.000 horsepower.

PHYSICS OF THE AIR.*

BY

W. J. HUMPHREYS,

Professor of Meteorological Physics, United States Weather Bureau.

CHAPTER XIV.

THE THUNDERSTORM.

Introduction.—A thunderstorm, as its name implies, is a storm characterized by thunder and lightning, just as a dust storm is characterized by a great quantity of flying dust. But the dust is never in any sense the cause of the storm that carries it along, nor, so far as is known, does either thunder or lightning have any influence on the course—genesis, development, and termination—of even those storms of which they form, in some respects, the most important features. No matter how impressive or how terrifying these phenomena may be, they never are anything more than mere incidents to, or products of, the peculiar storms they accompany, as will be made clear by what follows. In short, they are never in any sense either storm-originating or storm-controlling factors.

Origin of Thunderstorm Electricity.—Many have supposed that, whatever the genesis of the thunderstorm, the lightning, at least, is a product or manifestation of the free electricity always present in the atmosphere—normal atmospheric electricity. Observations, however (discussed later), seem definitely to exclude this assumption. Thus, while the difference in electrical potential between the surface of the earth and a point at constant elevation is, roughly, the same at all parts of the world, the number and intensity of thunderstorms vary greatly from place to place. Further, while the potential gradient at any given place is greatest in winter, the number of thunderstorms is most frequent in summer, and while the gradient in the lower layer of the atmosphere, at many places, usually is greatest from 8 to 10 o'clock, both morning and evening, and least at 2 to 3 o'clock P.M. and

* Continued from page 647, vol. 185, May, 1918.

3 to 4 o'clock A.M., no closely analogous relations hold for the thunderstorm.

But how, then, is the great amount of electricity incident to a thunderstorm generated? Fortunately an answer to this question based on careful experiments and numerous observations, and that greatly aids our understanding of the interrelations between the various thunderstorm phenomena, has been given by Dr. G. C. Simpson,[83] of the Indian Meteorological Department.

Doctor Simpson's observations, just referred to, were made at Simla, India, at an elevation of about 7000 feet above sea-level, and covered all of the monsoon seasons, roughly, April 15 to September 15, of 1908 and 1909. He also made observations of the electrical conditions of the snow at Simla during the winter of 1908–9.

A tipping bucket rain gauge gave an automatic, continuous record of the rate and time of rainfall, while a Benndorf [84] self-registering electrometer marked the sign and potential of the charge acquired during each two-minute interval. A second Benndorf electrometer recorded the potential gradients near the earth, and a coherer of the type used in radiotelegraphy registered the occurrence of each lightning discharge.

All obvious sources of error were examined and carefully guarded against. Hence it would seem that the conclusions drawn from the thousands of observations given in the memoir are fully justified; and especially so since several independent series of similar observations made at different times, by different people, and at places widely separated, have given confirmatory results in every case. Simpson's records show that—

(1) The electricity brought down by the rain was sometimes positive and sometimes negative.

(2) The total quantity of positive electricity brought down by the rain was 3.2 times greater than the total quantity of negative electricity.

(3) The period during which positively charged rain fell was 2.5 times longer than the period during which negatively charged rain fell.

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[83] Memoirs, Indian Meteorl. Dept., Simla, 1910, **20**, pt. 8; *Phil. Mag.*, **30**, 1, 1915.

[84] *Physikal. Ztschr.*, Leipzig, 1906, **7**, 98.

(4) Treating charged rain as equivalent to a vertical current of electricity, the current densities were generally smaller than 4×10^{-15} amperes per square centimetre; but on a few occasions greater current densities, both positive and negative, were recorded.

(5) Negative currents occurred less frequently than positive currents, and the greater the current density the greater the preponderance of the positive currents.

(6) The charge carried by the rain was generally less than 6 electrostatic units per cubic centimetre of water, but larger charges were occasionally recorded, and in one exceptional storm (May 13, 1908) the negative charge exceeded 19 electrostatic units per cubic centimetre.

(7) As stated in paragraph (3) above, positive electricity was recorded more frequently than negative, but the excess was the less marked the higher the charge on the rain.

(8) With all rates of rainfall positively charged rain occurred more frequently than negatively charged rain, and the relative frequency of positively charged rain increased rapidly with increased rate of rainfall. With rainfall of less than about 1 millimetre in two minutes, positively charged rain occurred twice as often as negatively charged rain, while with greater intensities it occurred 14 times as often.

(9) When the rain was falling at a less rate than about 0.6 millimetre in two minutes, the charge per cubic centimetre of water decreased as the intensity of the rain increased.

(10) With rainfall of greater intensity than about 0.6 millimetre in two minutes the positive charge carried per cubic centimetre of water was independent of the rate of rainfall, while the negative charge carried decreased as the rate of rainfall increased.

(11) During periods of rainfall the potential gradient was more often negative than positive, but there were no clear indications of a relationship between the sign of the charge and the sign of the potential gradient.

(12) The data do not suggest that the negative electricity occurs more frequently during any particular period of a storm than during any other.

Concerning his observation on the electrification of snow Doctor Simpson says:

So far as can be judged from the few measurements made during the winter of 1908–9, it would appear that—

(1) More positive than negative electricity is brought down by snow in the proportion of about 3.6 to 1.

(2) Positively charged snow falls more often than negatively charged.

(3) The vertical electric currents during snowstorms are, on the average, larger than during rainfall.

While these observations were being secured a number of well-devised experiments were made to determine the electrical effects of each obvious process that takes place in the thunderstorm.

Freezing and thawing, air friction, and other things were tried, but none produced any electrification. Finally, on allowing drops of distilled water to fall through a vertical blast of air of sufficient strength to produce some spray, positive and important results were found, showing:

(1) That breaking of drops of water is accompanied by the production of both positive and negative ions.

(2) That three times as many negative ions as positive ions are released.

Now, a strong upward current of air is one of the most conspicuous features of the thunderstorm. It is always evident in the turbulent cauliflower heads of the cumulus cloud—the parent, presumably, of all thunderstorms. Besides, its inference is compelled by the occurrence of hail, a frequent thunderstorm phe-

nomenon, whose formation requires the carrying of raindrops and the growing hailstones repeatedly to cold and therefore high altitudes. And from the existence of hail it is further inferred that an updraft of at least 8 metres per second must often occur within the body of the storm, since, as experiment shows,[85] air of normal density must have approximately this upward velocity to support the larger drops, those of 4 mm. or more in diameter, and, because of its greater weight, even a stronger updraft to support the average hailstone.

Experiment also shows [86] that raindrops of whatever size can not fall through air of normal density whose upward velocity is greater than about 8 metres per second, nor themselves fall with greater velocity through still air; that drops large enough, 4.5 mm. in diameter and up, if kept intact, to attain through the action of gravity a greater velocity than 8 metres per second with reference to the air, whether still or in motion, are so blown to pieces that the increased ratio of supporting area to total mass causes the resulting spray to be carried aloft or, at least, left behind, together with, of course, all original smaller drops. Above sea-level this limiting velocity is greater. It is given approximately by equating the weight of the drop, $4/3\ \pi\ r^3 g\ (\rho - \sigma)$, to the supporting force, $\pi\ r^2\ \sigma\ v^2$, roughly, in which r is the radius of the drop, ρ its density, σ the density of the air, v the velocity in question, and g the gravitational acceleration. Hence the limiting velocity increases in practically the same ratio that the square-root of the density decreases. Thus at an elevation of 3 kilometres above sea-level, where the barometric pressure is about 520 mm. and the temperature, say, 15° C. lower than at the surface, the limiting velocity is approximately 9.4 metres per second, instead of 8, the value for normal density, or density at 0° C. and 760 mm. pressure. Clearly, then, the updrafts within a cumulus cloud frequently must be strong and therefore break up at about the same level, that of maximum rain accumulation, innumerable drops which, through coalescence, have grown beyond the critical size, and thereby, according to Simpson's experiments, produce electrical separation within the cloud itself. Obviously, under the turmoil of a thunderstorm, such drops may be forced through the cycle of union (facilitated by any charges they may carry)

[85] P. Lenard, *Met. Zeit.*, vol. 21, p. 249, 1904.
[86] P. Lenard, *Met Zeit.*, vol. 21, p. 249, 1904.

and division, of coalescence and disruption, from one to many times, with the formation on each at every disruption, again *according to experiment,* of a correspondingly increased electrical charge. The turmoil compels mechanical contact between the drops, whereupon the disruptive equalization of their electrical potential breaks down their surface tensions and insures coalescence. Hence, once started, the electricity of a thunderstorm rapidly grows to a considerable maximum.

After a time the larger drops reach, here and there, places below which the updraft is small—the air cannot be rushing up everywhere—and then fall as positively charged rain, because of the processes just explained. The negative electrons, in the meantime, are carried up into the higher portions of the cumulus, where they unite with the cloud particles and thereby facilitate their coalescence into negatively charged drops. Hence the heavy rain of a thunderstorm should be positively charged, as it almost always is, and the gentler portions negatively charged, which also very frequently is the case.

Such in brief is Doctor Simpson's theory of the origin of the electricity in thunderstorms, a theory that fully accounts for the facts of observation and in turn is itself abundantly supported by laboratory tests and imitative experiments.

If this theory is correct—and it seems well founded—it must follow that the one essential to the formation of the giant cumulus cloud—namely, the rapid uprush of moist air—is also the one essential to the generation of the electricity of thunderstorms. Hence the reason why lightning seldom occurs except in connection with a cumulus cloud is understandable and obvious. It is simply because the electrifying process of splashing is vigorously active in this cloud and nearly absent in others.

The occasional lightning in connection with snowstorms, dust storms, and volcanic eruptions may in each case be due to the fact that the collision of solid particles produces electrification.[87]

The Violent Motions of Cumulus Clouds.—From observations, and from the graphic descriptions of the few balloonists and aviators who have experienced the trying ordeal of passing through the heart of a thunderstorm, it is known that there is violent vertical motion and much turbulence in the middle of a large cumulus cloud, a fact which, so far as it relates to the

[87] Rudge, *Proc. Roy. Soc., A,* **90,** 256, 1914.

theory alone of the thunderstorm, it would be sufficient to accept without inquiring into its cause. However, to render the discussion more nearly complete, it perhaps is worth while, since it is a mooted question, to inquire what the probable cause of the violent motions in large cumulus clouds really is—motions which, in the magnitude of their vertical components and degree of turmoil, are never exhibited by clouds of any other type nor met with elsewhere by either kites or balloons of any kind, manned, sounding, or pilot.

It has been shown by von Bezold [88] that sudden condensation from a state of supersaturation, and also sudden congelation of undercooled cloud droplets, would, as a result of the heat thus liberated, cause an equally sudden expansion of the atmosphere, and thereby turbulent motions analogous to those observed in large cumuli. However, as von Bezold himself points out, it is not evident how either the condensation or the freezing could suddenly take place throughout a cloud volume great enough to produce the observed effects. Besides, these eruptive turmoils, whatever their genesis, undoubtedly originate and run their course in regions already filled with cloud particles in the presence of which no appreciable degree of supersaturation can occur. Hence the rapid uprush and the violent turbulence in question obviously must have some other cause, which indeed is provided by the difference between the actual temperature gradient of the surrounding atmosphere and the adiabatic temperature gradient of the saturated air within the cloud itself.

Consider a warm summer afternoon, temperature 30° C., and assume the dew-point to be 18° C. Now, the adiabatic decrease of temperature of non-saturated air is about 1° C. per 100 metres increase in elevation, and therefore, under the assumed conditions, vertical convection of the surface air causes condensation to begin at an elevation of approximately 1.5 kilometres—allowing for the increase of volume per unit mass of vapor. From this level, however, so long as the cloud particles are carried up with the rising air, the rate of temperature decrease for at least a couple of kilometres is much less—at first about one-half the previous rate. After a considerable rise above the level of initial condensation, half a kilometre, say, the raindrops have so increased in size as to lag behind the upward current and even to

[88] *Sitzber. K. preuss. Akad. d. Wiss.*, Berlin, 1892, **8**, 279–309.

drop out, while at the same time the amount of moisture condensed per degree fall of temperature grows rapidly less, as shown by the saturation adiabats of Fig. 60. Hence for both reasons—because the heat of the water is no longer available to the air from which it was condensed, the drops having been left behind, and because a decreasing amount of latent heat is to be had from further condensation, there being less and less precipitation per degree cooling—the rate of temperature decrease again approaches the adiabatic gradient of dry air, or 1° C. per 100 metres change of elevation.

Obviously, then, for some distance above the level at which condensation begins to set free its latent heat the temperature of the rising mass of moist air departs farther and farther from the temperature of the surrounding atmosphere at the same level, and therefore its buoyancy for a time as steadily increases. But, of course, as explained above, this increase of buoyancy does not continue to any great altitude.

In the lower atmosphere continuous and progressive convection builds up the adiabatic gradient so gradually that no great difference between the temperature of the rising column and that of the adjacent atmosphere is anywhere possible. Hence, under ordinary conditions, the uprush in this region is never violent. But whenever the vertical movement of the air brings about a considerable condensation it follows, as above explained, that there is likely to be an increase in its buoyancy, and hence a more or less rapid upward movement of the central portion, like air up a heated chimney, and for the same reason, together with, because of viscosity, a rolling and turbulent motion of the sides, of the type so often seen in towering cumulus clouds. Obviously, too, the uprushing column of air must continue to gain in velocity so long as its temperature is greater, or density less, than that of the surrounding atmosphere, except as modified by viscosity, and therefore have its greatest velocity near the level at which these two temperatures are the same. Hence the rising column must ascend somewhat beyond its point of equilibrium, and then, because slightly undercooled, correspondingly drop back.

Fig. 82, based upon approximately average conditions, illustrates the points just explained. The elevation is in kilometres and the temperature in degrees Centigrade.

AB is the adiabatic temperature gradient for non-saturated

air, about 1° C. per 100 metres change in elevation. *GCKDEF* is the supposed temperature gradient before convection begins, or a decrease, in accordance with observations, of 6° C., about, per kilometre increase in elevation, except near the surface, where the temperature decrease, before convection has begun, ordinarily is less rapid, and at elevations between 5 kilometres, roughly, and the isothermal level, where it is more rapid.

As convection sets in, the temperature decrease near the surface soon approximates the adiabatic gradient for dry air, and this condition extends gradually to greater altitudes, till, in the given case, condensation begins at the level *C*, or where the temperature is 15° C. Here the temperature decrease, under the assumed conditions, suddenly changes from 10° C. per kilometre increase of elevation to rather less than half that amount, but slowly increases with increase of altitude and consequent decrease of temperature. At some level, as *L*, the temperature difference between the rising and the adjacent air is a maximum. At *D* the temperature of the rising air is the same as that of the air adjacent, but its momentum presumably carries it on to some such level as *H*. Within the rising column, then, the temperature gradient is given approximately by the curve *ACLDHE*, while that of the surrounding air is substantially as shown by the curve *ACKDEF*.

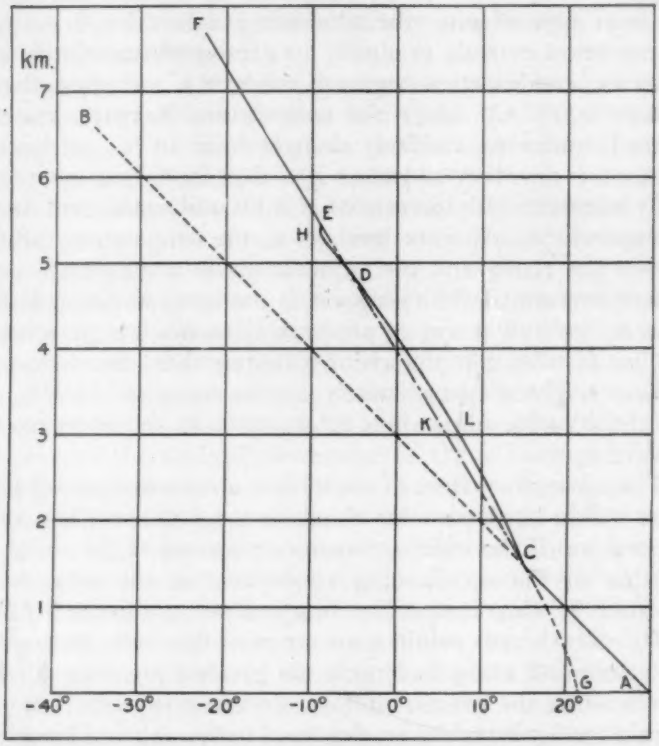
The cause, therefore, of the violent uprush and turbulent condition within large cumulus clouds is the difference between the temperature of the inner or warmer portions of the cloud itself and that of the surrounding atmosphere at the same level as indicated by their respective temperature gradients *CLD* and *CKD*. Clearly, too, while some air must flow into the condensation column all along its length, the greatest pressure difference, and therefore the greatest inflow, obviously is at its base. After the rain has set in, however, this basal inflow is from immediately in front of the storm, and necessarily so, as will be explained later.

The approximate difference in level between *D* and *H*, or the height to which the momentum of the ascending column will force it to rise after it has cooled to the temperature of the surrounding air, may easily be computed in terms of the vertical velocity at *D* and the difference between the temperature gradients of the rising and the non-rising masses of air. Let the vertical velocity of the rising column be *V* centimetres per second at *D;* let the average

absolute temperature between D and H be T; and let the difference between the temperature of the rising air and the surrounding air change uniformly at the rate δT per centimetre change of elevation.

Obviously the kinetic energy of the rising air at D will be used up in lifting it to some greater elevation. But the weight of a

FIG. 82.



Temperature gradients within (CLD) and without (CKD) cumulus clouds.

mass m of this air is not mg (g being gravity acceleration), which it would be *in vacuo*, but $mg\left(\frac{\rho-\sigma}{\rho}\right)$, in which ρ is the density of the air in question and σ the density of the surrounding air. Thus at h centimetres above D $\rho-\delta=\frac{h\,\delta\,T}{T}\rho$, approximately, and therefore the weight of the mass m at this level $m\,g\,\frac{h\,\delta\,T}{T}$, approx-

imately. Hence the work in lifting the mass m through this altitude h is its average weight, $\frac{mg\,h\,\delta\,T}{2\,T}$, multiplied by the distance h.

Hence $\frac{1}{2}\,m\,V^2 = m\,g\,x^2\frac{\delta\,T}{2\,T}$ or $x^2 = \frac{V^2\,T}{g\,\delta\,T}$

in which x, directly proportional to V, is the height in centimetres to which the air will rise above D.

Let $T = 265°$ C. absolute, corresponding to the conditions shown in Fig. 82; let the temperature gradient be 6° C. per kilometre in the free air and 8° C. per kilometre in the rising air, and $\delta\,T$ the temperature change between the two per centimetre change of elevation, therefore 1/50000; and let $V = 12$ metres per second, then

$$x = 1200\sqrt{\frac{5\times 10^4\times 265}{980}} = 1.395 \text{ kilometres.}$$

Since the height of the barometer at an elevation of 5 kilometres above sea-level is, roughly, 400 mm., and since the supporting force of an updraft is proportional to the product of its density by the square of its velocity, it follows that the vertical velocity in metres per second necessary to support the largest drops at this elevation is given by the equation,

$$V = v\sqrt{\frac{760}{400}},$$

in which v is the required velocity at normal density. But, as above explained, $v = 8$ metres per second, about, and therefore $V = 11$ metres per second, approximately.

Hence the above assumption that the vertical velocity at D is 12 metres per second appears to be conservative.

Viscosity between the rising and the adjacent air prevents the actual height attained from being quite equal to the above theoretical value; nevertheless, the maximum elevation, or what might be called the " momentum level " often, especially in the case of the largest and most active cumulus clouds, is much greater than the equilibrium level.

Convectional Instability.—Rapid vertical convection of humid air, as we have seen, is essential to the production of the cumulus cloud and, therefore, to the generation of the thunderstorm. Hence it is essential to consider the conditions under which the vertical temperature gradient necessary to this convection can be established. These are:

1. Strong surface heating, especially in regions of light winds; a frequent occurrence.

The condition that the winds be light is not essential, or perhaps even favorable, to the genesis of all thunderstorms—only the local or heat variety, and favorable to these simply because winds, by thoroughly mixing the air, prevent the formation of isolated rising columns, the progenitors of this particular type of storm.

2. The overrunning of one layer of air by another at a temperature sufficiently lower to induce convection. This apparently is the cause of practically all ocean thunderstorms. It seems also to be the chief cause of those that so frequently occur on land in connection with cyclones.

3. The underrunning and consequent uplift of a saturated layer of air by a denser layer; a frequent occurrence to a greater or less extent and presumably, therefore, at least an occasional one of sufficient magnitude to produce a thunderstorm.

Here the underrunning air lifts both the saturated layer and the superincumbent unsaturated layer, and thereby forces each to cool adiabatically. But as both layers are lifted equally, while, because of the latent heat of condensation, the saturated layer cools much slower than the dry, it follows that a sufficient mechanical lift of a saturated layer of air would establish between it and the non-saturated layer above a superadiabatic temperature gradient and thereby produce local convection, cumulus clouds, and perhaps a thunderstorm.

Periodic Recurrence of Thunderstorms.—While thunderstorms may develop at any hour of any day, they nevertheless have three distinct periods of maximum occurrence: (*a*) Daily, (*b*) yearly, and (*c*) irregularly cyclic. Each maximum depends upon the simple facts that the more humid the air and the more rapid the local vertical convections the more frequent and also the more intense the thunderstorms, for the obvious reason that it is rapid vertical convection of humid air that produces them.

Daily Land Period.—Vertical convection of the atmosphere over land areas reaches its greatest altitudes and thereby produces the heaviest condensation and largest cumulus clouds when the surface is most heated; that is, during afternoons. Hence the

hours of maximum frequency of inland or continental thunderstorms are, in most places, 2 to 4 P.M.

Daily Ocean Period.—Because of the great amount of heat rendered latent by evaporation, because of the considerable depth to which the sea is penetrated by solar radiation, and because of the high specific heat of water, the surface temperature of the ocean increases but little during the day, and because of convection or the sinking of any surface water that has appreciably cooled and the bringing of the warmest water always to the top, it decreases but slightly at night. Indeed, the diurnal temperature range of the ocean surface usually is but a small fraction of one degree C., while that of the atmosphere at from 500 to 1000 metres elevation is several fold as great.[89] Hence those temperature gradients over the ocean that are favorable to rapid vertical convection are most frequent during the early morning hours, and therefore the maximum of ocean thunderstorms usually occurs between midnight and 4 A.M.

Yearly Land Period.—Just as inland thunderstorms are most frequent during the hottest hours of the day, so, too, and for the same reason, they are, in general, most frequent over the land during the hottest months of the year, or rather during those months when the amount of surface heating, and therefore the vertical temperature gradient, is a maximum. This will be better understood by reference to the winter and summer gradients of Fig. 15, determined, as previously explained, by averaging 52 and 65 records, respectively, obtained by sounding balloons sent up from Munich, Strassburg, Trappes, and Uccle, places of about the same latitude and having generally similar climates. It will be seen that the temperature of the air not only is much higher at all levels during summer than during winter, but also decreases through the first three kilometres much more rapidly.

That this important difference between the temperature gradients of winter and summer is general and not peculiar to the above localities is obvious from the fact that during summer the surface of the earth gradually grows warmer and therefore induces correspondingly frequent and vigorous convection, while during winter it as steadily becomes colder and therefore only occasionally, at the times of temporary warming, induces con-

[89] Braak, *Beitr. z. Physik d. fr. Atmosph.*, Leipzig, 1914, **6**, 141.

vections strong enough to form large and well-defined cumulus clouds.

From these several considerations it is evident that:

a. Winter convections cannot, in general, rise to nearly so great altitudes nor with such velocity as those of summer.

b. The absolute humidity of summer air may at times be greatly in excess of that of winter.

c. The winter snow level usually is much below that of summer.

Hence thunderstorms, since they depend, as explained, upon the action of strong vertical convection on an abundance of *rain* drops, necessarily occur most frequently during the warmer seasons, and only occasionally during the colder months. In middle latitudes, where there are no late spring snows to hold back the temperatures, the month of maximum frequency is June. In higher latitudes, where strong surface heating is more or less delayed, the maximum occurs in July or even August.

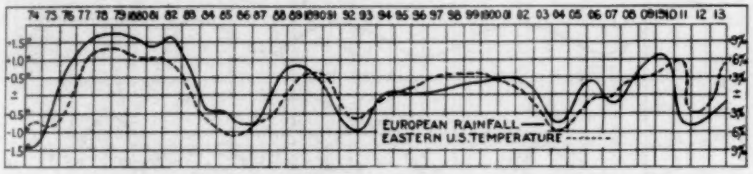
Yearly Ocean Period.—Over the oceans, on the other hand, temperature gradients favorable to the genesis of thunderstorms, and therefore the storms themselves, occur most frequently during winter and least frequently during summer. This is because the temperature of the air at some distance above the surface, being largely what it was when it left the windward continent, greatly changes from season to season, while that of the water, and, of course, the air in contact with it, changes relatively but little through the year. That is, over the oceans the average decrease of temperature with increase of elevation obviously is least and, therefore, thunderstorms fewest in summer, and greatest, with such storms most numerous, in winter.

Cyclic Land Period.—Since thunderstorms are accompanied by rain and since over land they are most numerous during summer, it would appear that they must occur most frequently either in warm or in wet years and least frequently in cold or in dry years. Further, if it should happen, as it actually does, that, for the earth as a whole, warm years are also wet years and dry years cold years, it would appear logically certain that, for the entire world, the maxima numbers of thunderstorms must belong to the years that are wet and warm and the minima to those that are cold and dry.

A complete statistical examination of these statements is not

possible, owing to the fact that meteorological data are available for only portions of the earth's surface and not for the whole of it. Nevertheless, well-nigh conclusive data do exist. The annual rainfall, for instance, to the leeward of a large body of water obviously must bear the same relation to the annual average windward temperature that the total annual precipitation over the entire world does to the annual average world temperature. In each case the amount of evaporation or amount of water vapor taken into the atmosphere, and therefore the amount of subsequent precipitation, clearly must increase and decrease with the temperature. An excellent test and complete support of this deduction is furnished by Fig. 83, in which the full line represents the smoothed annual European precipitation,[90] and the dotted

FIG. 83.



Relation of European rainfall to eastern United States temperature.

line smoothed annual average temperatures over the eastern United States. Obviously, as supported by the data graphically represented in Fig. 83, the warmer the air as it leaves America the greater the moisture it must take up in its passage across the Atlantic, and therefore the greater its supply of humidity on reaching Europe and the heavier the subsequent precipitation. Clearly, too, the same relations must apply to the entire earth that so obviously should and so demonstrably do hold for the North Atlantic and its adjacent continents.

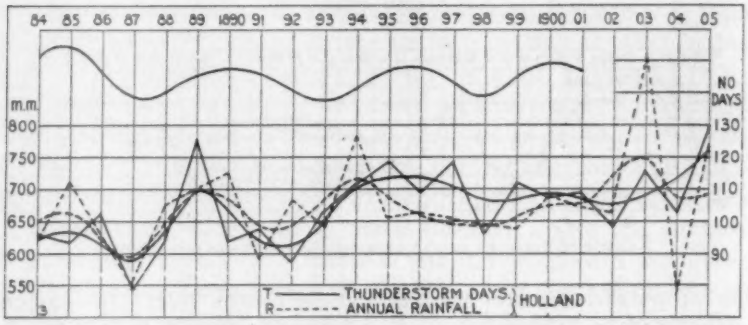
Beyond a reasonable doubt, therefore, for the world as a whole, warm years are wet and cold ones are dry. Hence, as above stated, it is practically certain that the maxima of thunderstorms occur during years that are wet, or warm—for the two are synchronous—and the minima during years that are dry or cold. A partial and, so far as it goes, a confirmatory statistical test of

[90] Hellmann, "Die Niederschläge in den Norddeutschen Stromgebieten," Berlin, 1906, vol. 1, pp. 336–337, and elsewhere.

this conclusion is given by Fig. 84. The lower group of curves is based on an exhaustive study by Dr. von Gulik[91] of thunderstorms and lightning injuries in Holland. The continuous zigzag line gives the actual number of thunderstorm days, and the continuous curved line the same numbers smoothed. The broken lines give, respectively, the actual and the smoothed values of the annual average precipitation. The upper curve represents the variations in the smoothed number of destructive thunderstorms[92] (number of thunderstorm days not readily available) in Germany.

The original data on which this last curve is based indicate a continuous and rapid increase of thunderstorm destructiveness throughout the period studied, 1854–1901. Presumably, how-

FIG. 84.



Relation of annual number of thunderstorm days to total annual precipitation—Holland. The uppermost wavy curve shows the variation in the smoothed number of destructive thunderstorms in Germany.

ever, this increase is real only to the extent that the country has become more densely populated and more thickly studded with destructible property. Since thunderstorms are caused by rapid vertical convection and heavy condensation, and since the temperature of the air upon which these in turn depend has not, on the decade average, measurably changed since reliable records began, at least a hundred years ago, there clearly is no logical reason for believing that the decade average either of the frequency or the intensity of the storms themselves has materially changed during that time. At any rate, this element—that is, the

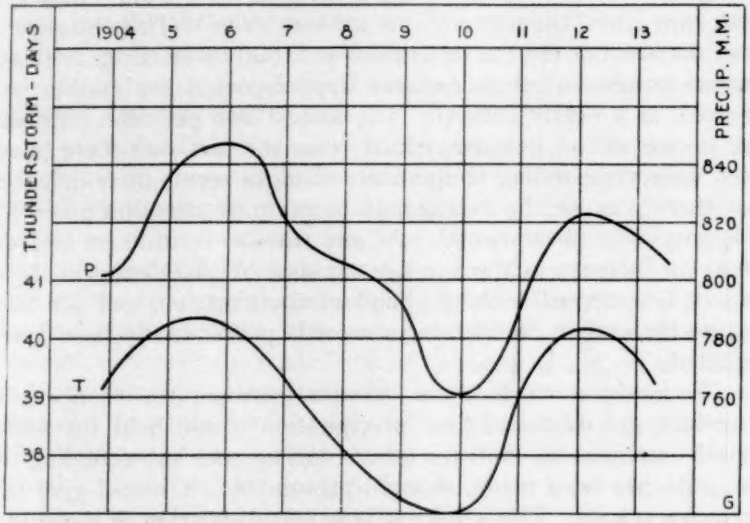
[91] *Meteorologische Zeitschrift*, Braunschweig, 1908, 25th Jhrg., 108.

[92] Otto Steffens, *Ztschr. f. d. gesamte Versicherungswiss.*, Berlin, 1904, 4, pt. 4. (Also Diss.-Berlin, 1904.)

rapid increase suggested by insurance data—has been omitted from the curve and only the fluctuation factor retained.

It will be noticed that the curve of thunderstorm frequency for all Holland closely parallels the curve of thunderstorm injury in all Germany. Hence it seems safe to infer that the frequency of thunderstorm varies pretty much the same way over both countries, and presumably also over many other portions of Europe; that is, roughly as the rainfall varies, or, considering the world as a whole, roughly as the temperature varies.

FIG. 85.



Relation of annual number of thunderstorm days, *T*, to total precipitation, *P*—United States.

Additional statistical evidence of the relation between the annual number of thunderstorm days and the total annual precipitation, kindly furnished by P. C. Day, in charge of the Climatological Division of the Weather Bureau, is shown by Fig. 85, in which the upper line gives, in millimetres, the smoothed annual precipitation of 127 stations scattered over the whole of the United States, and the lower line the smoothed average annual number of thunderstorm days at these same stations. It was thought at first that this relation might differ greatly for those portions of the United States whose climates are radically dissimilar, and for this reason the stations east of the one hundredth meridian provisionally were classed separately from those west of

it; but the results for the two sections, being substantially alike, show that for this purpose their division is entirely unnecessary.

As will be seen from the figure, the earliest statistics used are those of 1904. This is because the annual number of such days reported rapidly decreases from 1904 back to about 1890. Indeed, the annual number of thunderstorm days reported per station since 1903 is almost double the annual number per station (practically the same stations) from 1880 to 1890. The transition from the smaller to the larger number was due in great measure, doubtless, to an alteration in station regulations equivalent to changing the official definition of a thunderstorm from "thunder *with* rain" to "thunder *with* or *without* rain." This, however, does not account for the fact that from 1890 to 1904 the average annual number of thunderstorm days reported per station increased, at a nearly constant rate, almost 100 per cent. Either the storms did so increase, which from the fact that there have been no corresponding temperature changes seems incredible, or else there was, on the average, an increase of attention given to this particular phenomenon. At any rate, so continuous and so great an increase in the average number of thunderstorm days cannot be accepted without abundant confirmation, and for this reason the earlier thunderstorm records provisionally have been rejected.

Obviously a much closer relation between the number of thunderstorm days and total precipitation would hold for some months and seasons than for others, but no such sub-grouping of the data has been made, though, presumably, it would give interesting results. The whole purpose of this portion of the study was to arrive at some definite idea in regard to the cyclic change of thunderstorm frequency, to see with what other meteorological phenomena this change is associated, and, if possible, to determine its cause.

Now, it is well known that the average temperature of the world as a whole follows in general the sun-spot changes, in the sense that the greater the number of spots the lower the temperature, and the smaller the number of spots the higher the temperature. This regular relation, however, often is greatly modified [93] by the presence in the high atmosphere of volcanic dust,

[93] Humphreys, W. J., *Bull. Mount Weather Observatory*, Washington, 1913, **6**, 1.

one invariable effect of which is a lower average temperature. Hence the warm and the cold periods are irregularly cyclic, and also irregular in intensity. Hence, also, the annual amount of precipitation, the frequency of thunderstorms, and many other phenomena must perforce undergo exactly the same irregular cyclic variation.

As already stated, the statistical evidence bearing on these conclusions neither is nor can be complete, but the deductions are so obvious and the statistical data already examined so confirmatory that but little doubt can exist of their general accuracy.

Cyclic Ocean Period.—The record of thunderstorms over the ocean is not sufficiently full to justify any conclusions in regard to their cyclic changes. Possibly, as in the yearly and the daily periods, the ocean cyclic period may be just the reverse of that of the land, but this is not certain.

Geographic Distribution.—The geographic distribution of the thunderstorm may safely be inferred from the fact that it is caused by the strong vertical convection of humid air. From the nature of its formation one would assume—and the assumption is supported by observation—that the thunderstorm must be rare beyond either polar circle, especially over Greenland and over the Antarctic continent, rare over great desert regions wherever situated, rare over the trade belts of the oceans, and, on the other hand, increasingly abundant with increase of temperature and humidity, and therefore, in general, most abundant in the more rainy portions of the equatorial regions. The east coast of South America, from Pernambuco to Bahia, is said to be an exception.

An interesting and instructive example of the annual geographic distribution of thunderstorms is given by Fig 86, copied from a statistical study of this subject by W. H. Alexander.[94] Although this example, based on a ten-year (1904–1913) average, refers to only the United States and southern Canada, it nevertheless shows the great influence of humidity, latitude, and topography on thunderstorm frequency.

One of the most striking facts shown by this map is the relatively unusual occurrence of this phenomenon along the Pacific Coast. This exceptional condition is explained by the fact that during the summer time, or season of strong vertical convection, the temperature of the on-shore winds of that region is too low

[94] *Monthly Weather Review*, **43**, p. 322, 1915.

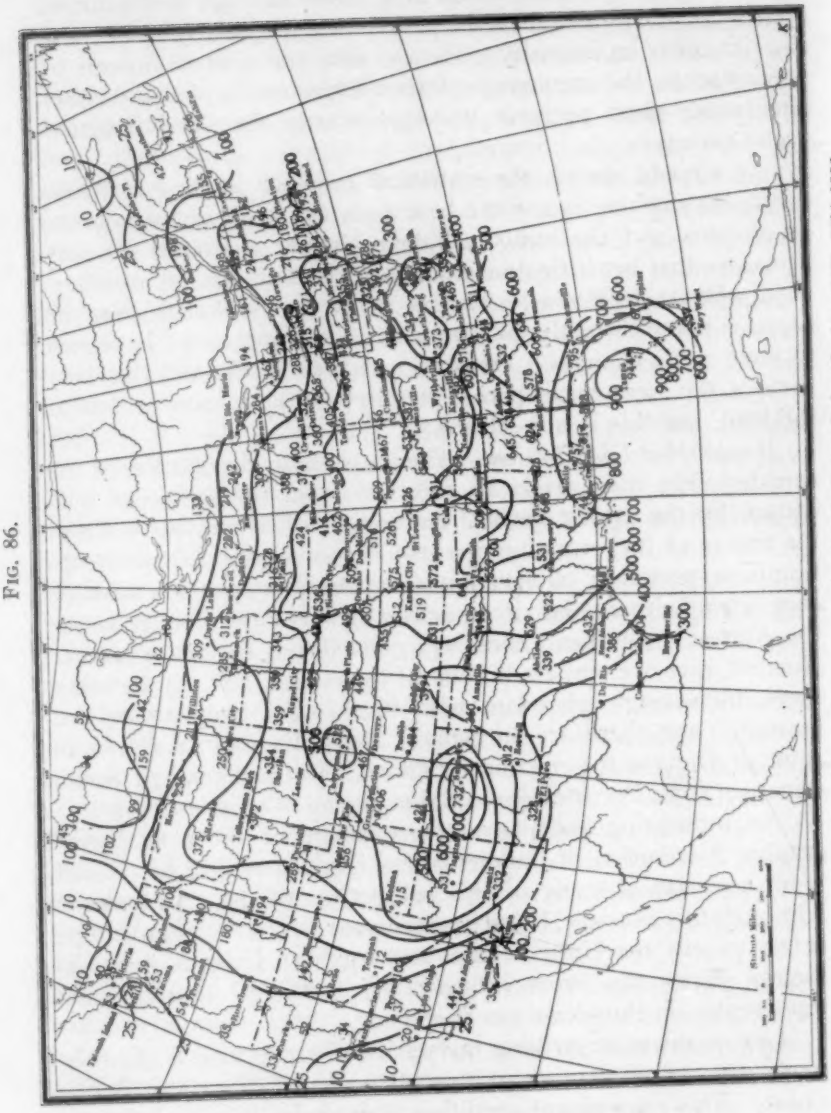


FIG. 86.

Total number of thunderstorm days in the United States during the ten years, 1904–1913, inclusive. (Alexander.)

and their humidity too small to permit of the ready formation over the heated interior of abundant cumuli, without which, as already explained, thunderstorms do not occur.

Pressure and Temperature Distribution.—In illustrating the occurrence of thunderstorms with reference to the disposition of isobars and isotherms, or the distribution of atmospheric pressure and temperature, typical weather maps of the United States,[95] Figs. 87 to 101, have been used, not because the thunderstorms of this country are different in any essential particular from those of other countries, but chiefly as a matter of convenience in making the drawings. To facilitate their study, each of the several types discussed is illustrated with three consecutive maps. The first shows the 12-hour antecedent conditions, the second the particular pressure-temperature distribution in question, and the third the 12-hour subsequent conditions.

In these figures the isobars, in corrected inches of mercury as read on the barometer and reduced to sea-level, and the isotherms in Fahrenheit degrees, are marked by full and dotted lines respectively. The legend " LOW " is written over a region from which, for some distance in every horizontal direction, the pressure increases. Similarly, the legend " HIGH " applies to a region from which, in every horizontal direction, the pressure decreases. The arrows, as is customary on such maps, fly with the wind, while the state of weather is indicated by the usual U. S. Weather Bureau symbols.

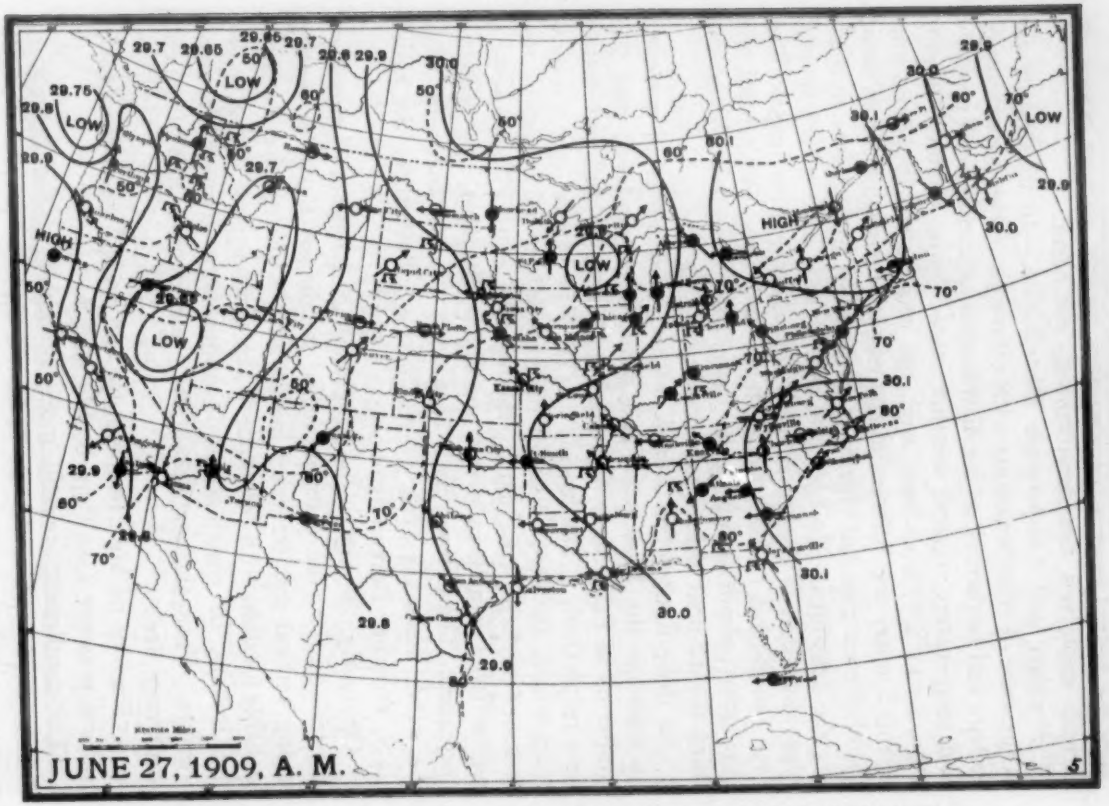
Obviously, the key to the geographic distribution of thunderstorms—that is, the distribution of conditions likely to induce strong vertical convection of humid air—is also the key to their probable location with reference to any given system of isotherms and isobars, or distribution of atmospheric temperature and pressure. From this standpoint the places of their most frequent occurrence are:

a. Regions of high temperature and widely extended nearly uniform pressure (see Figs. 87, 88, and 89).

The conditions are still more favorable to the genesis of thunderstorms when the air is humid and the pressure, partly

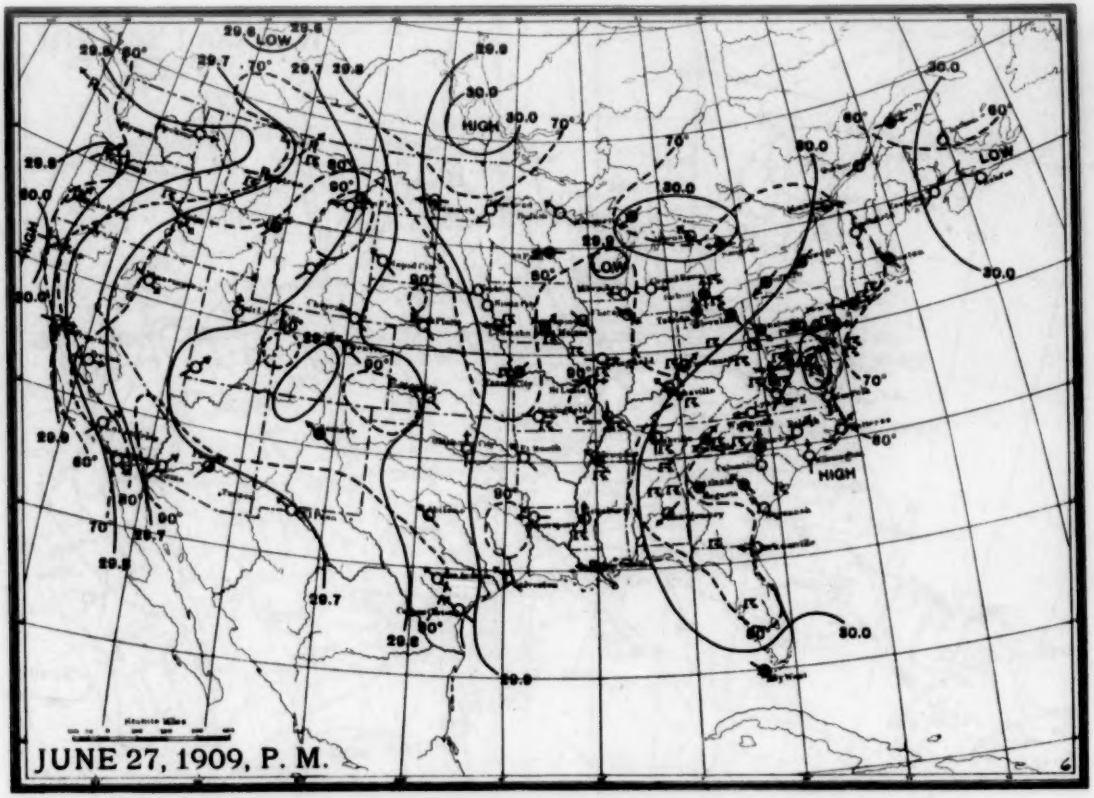
[95] The author wishes to acknowledge the kind coöperation of the official forecasters of the U. S. Weather Bureau in selecting maps typical of thunderstorm conditions in the United States.

FIG. 87.



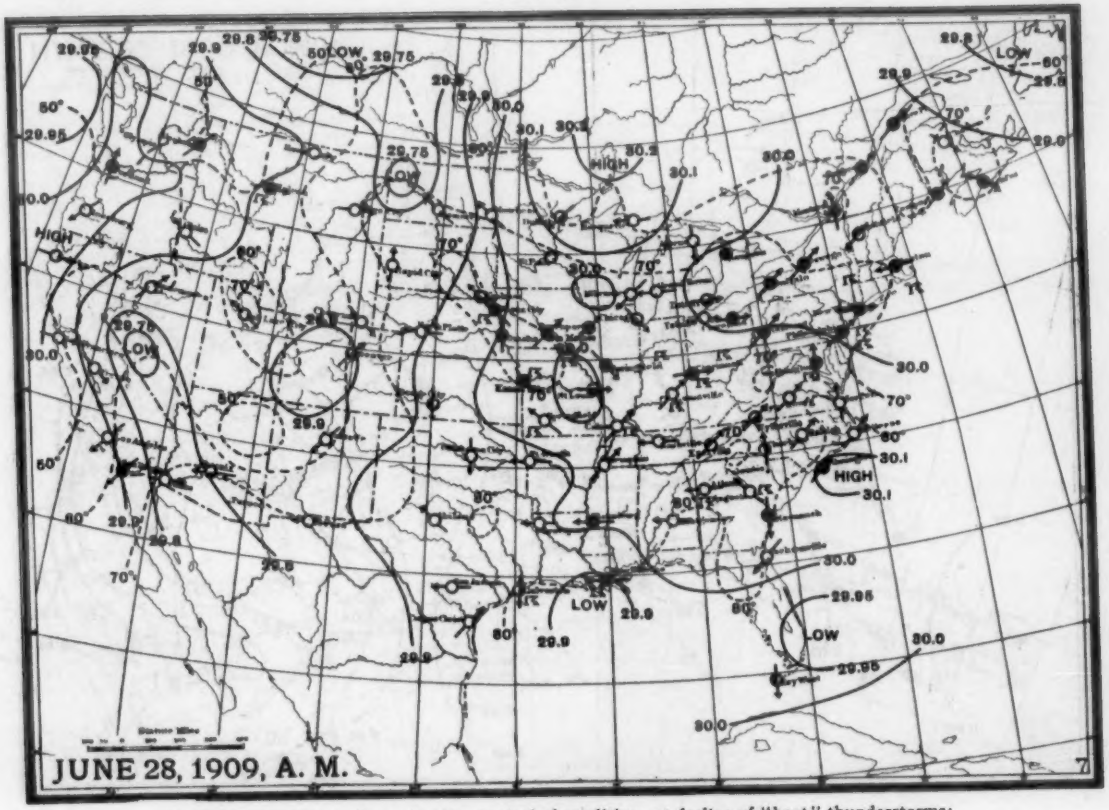
Weather map, 8 A.M., June 27, 1909, typical conditions at beginning of "heat" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; K, thunderstorm.

FIG. 88.



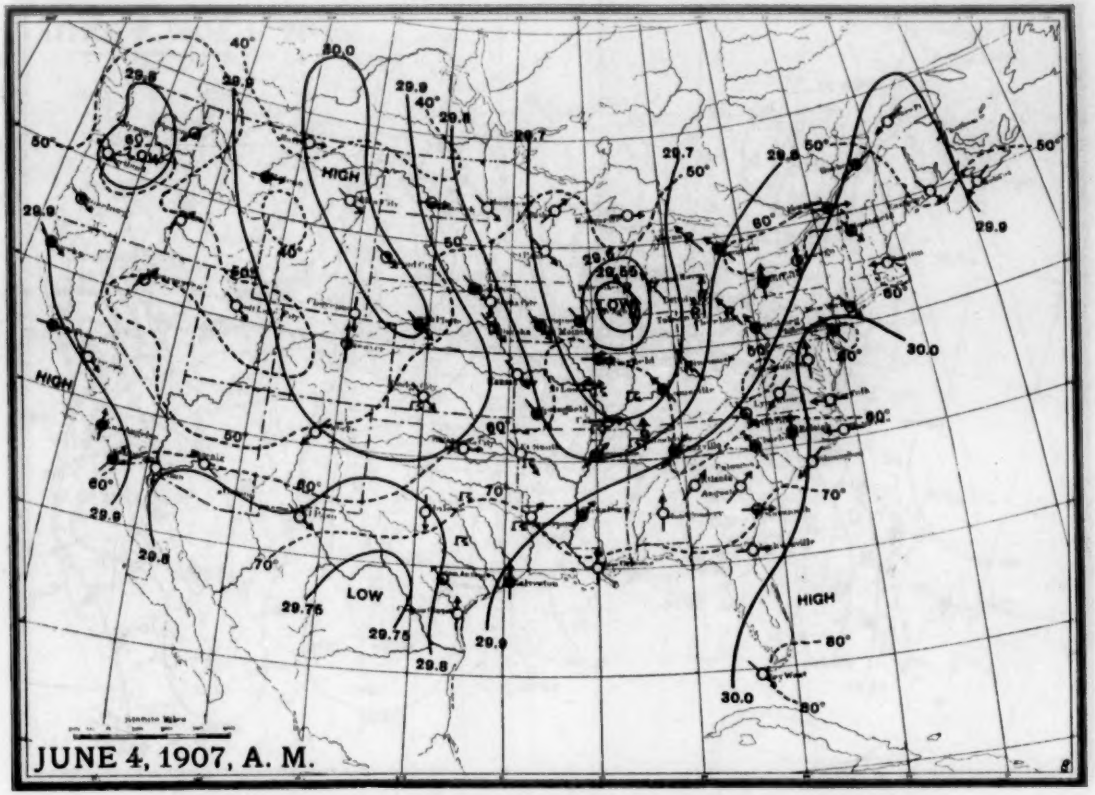
Weather map, 8 P.M., June 27, 1909, typical of "heat" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 89.



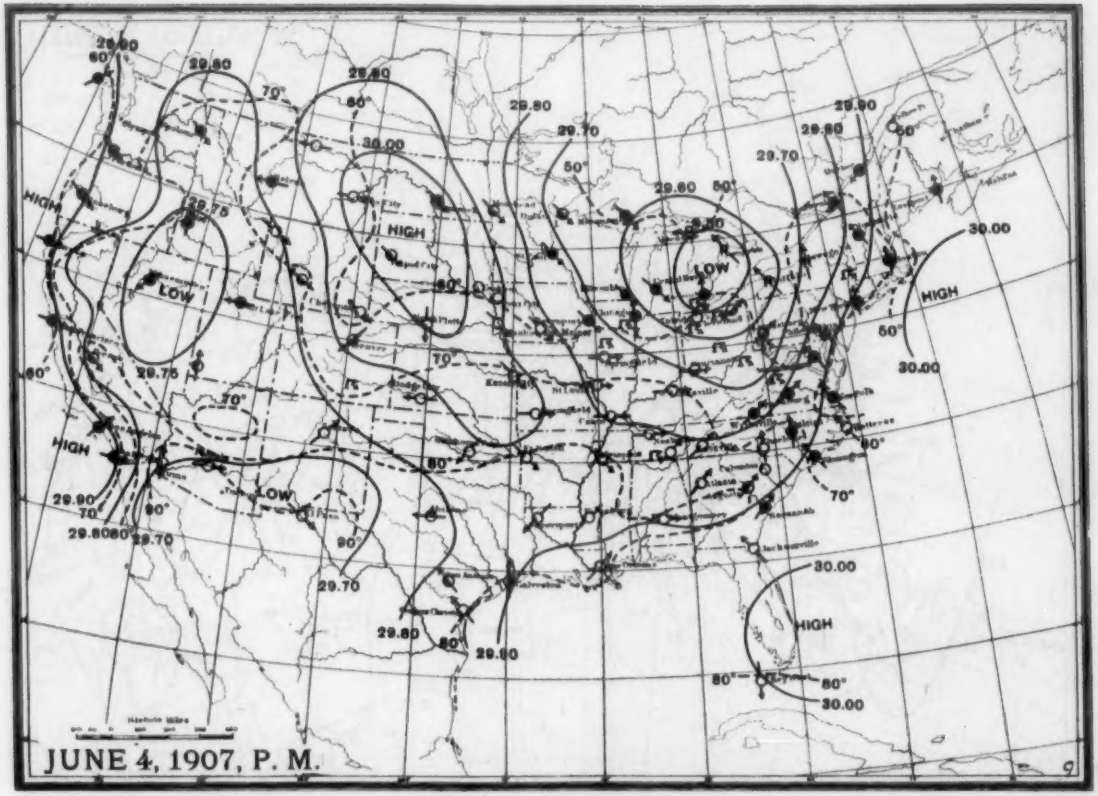
Weather map, 8 A.M., June 28, 1909, typical of conditions at decline of "heat" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 90.



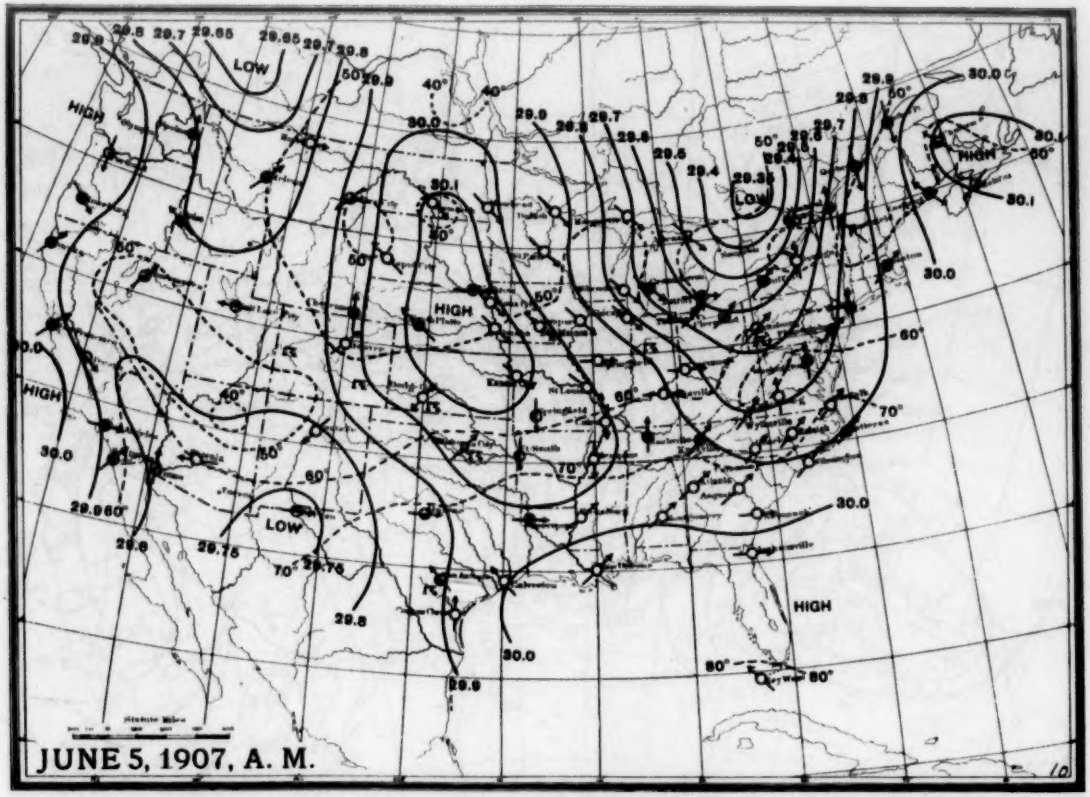
Weather map, 8 A.M., June 4, 1907, typical of conditions at beginning of "cyclonic" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 91.



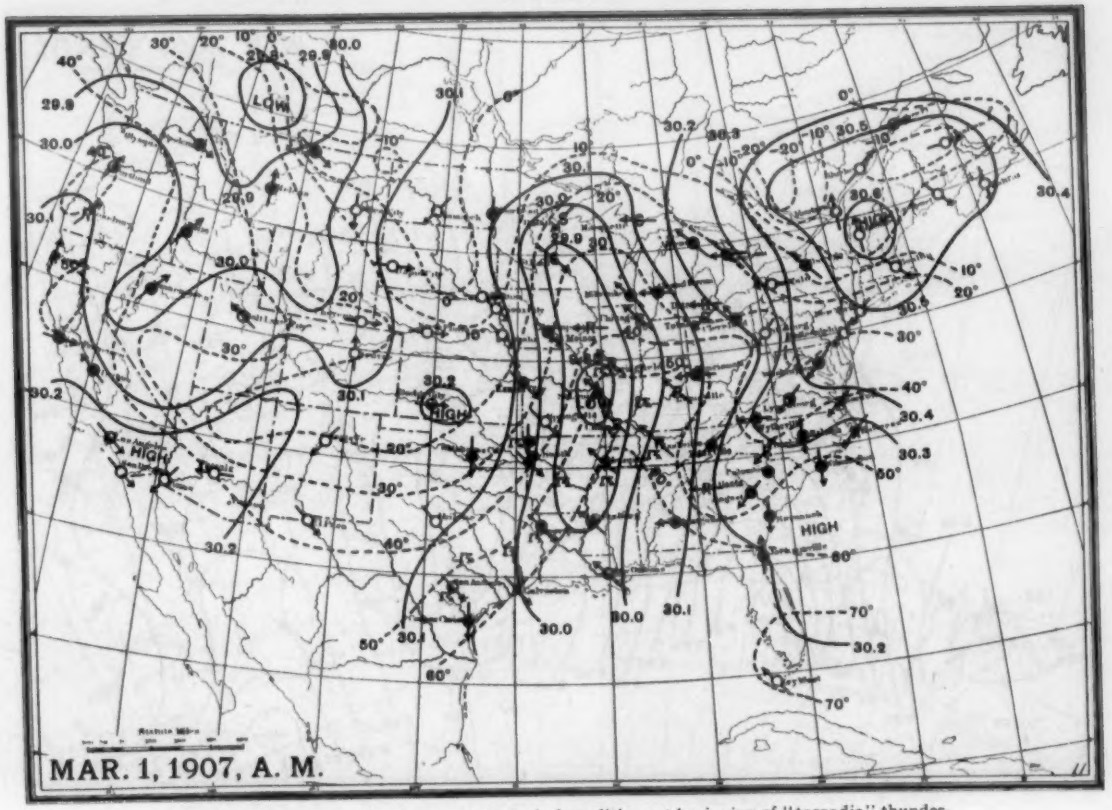
Weathermap, 8 P.M., June 4, 1907, typical of "cyclonic" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 92.



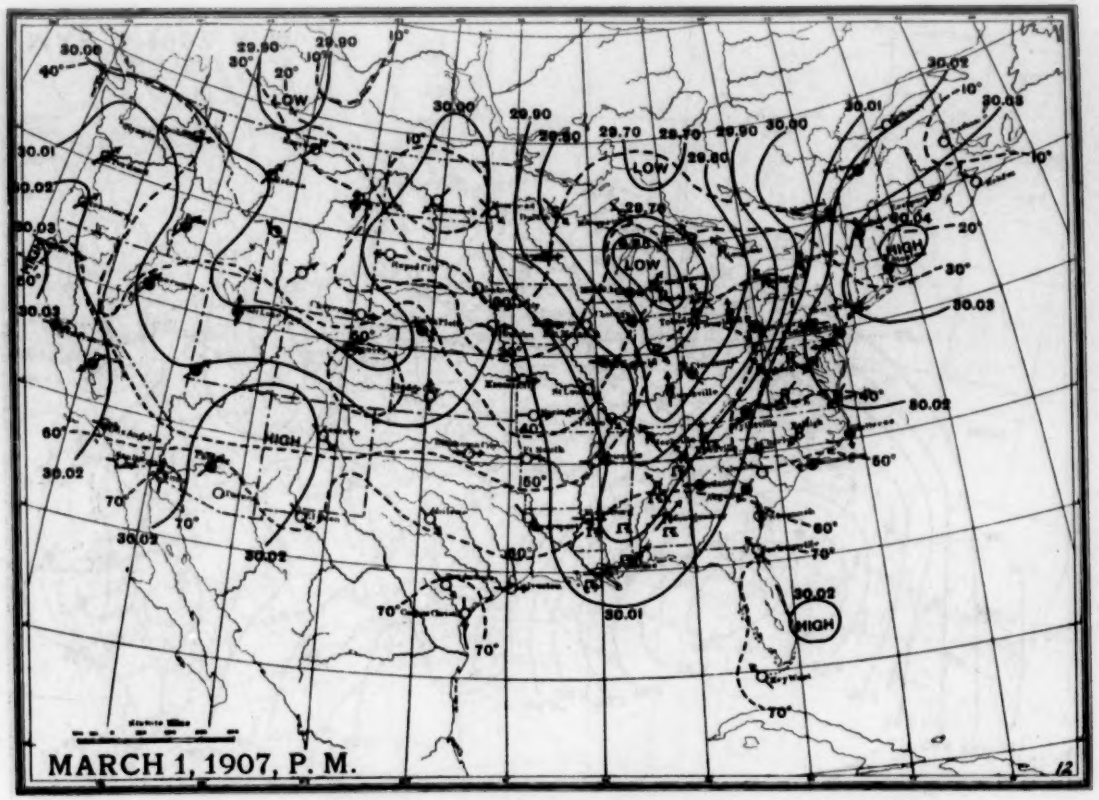
Weather map, 8 A.M., June 5, 1907, typical of conditions at decline of "cyclonic" thunderstorms:
○ clear; ◗, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 93.



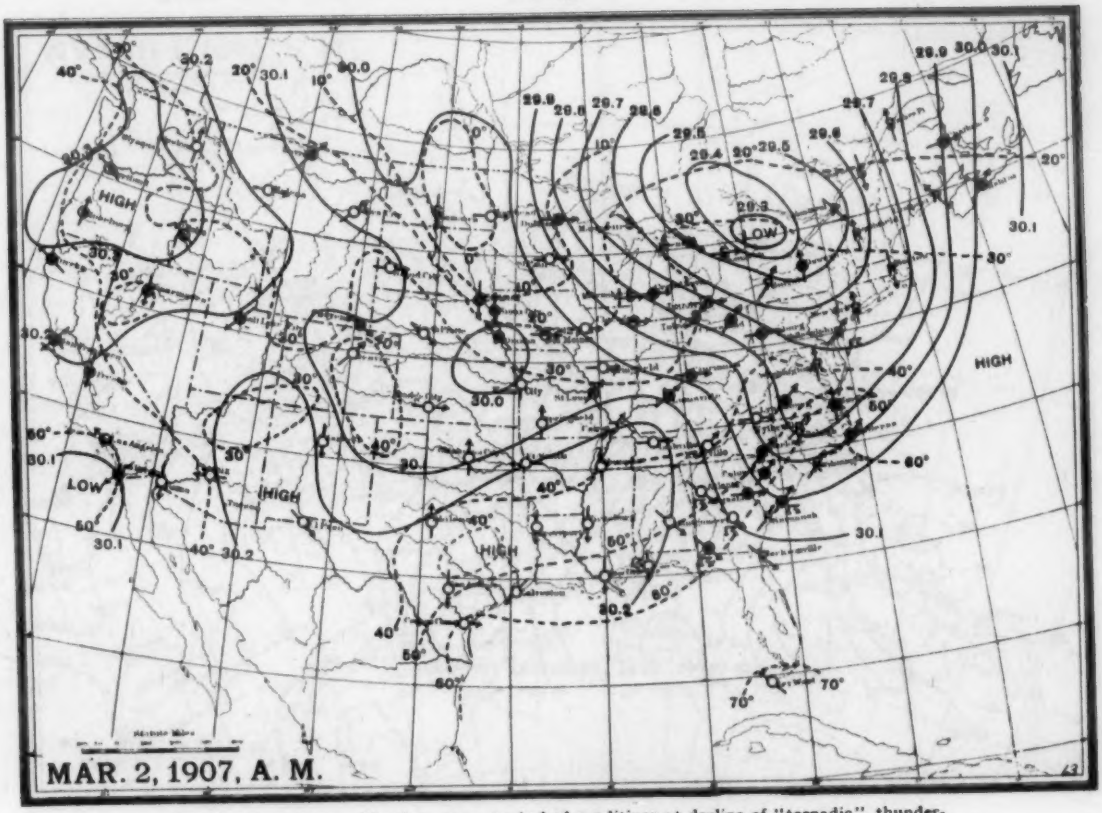
Weather map, 8 A.M., March 1, 1907, typical of conditions at beginning of "tornadic" thunderstorms: ○, clear; ◗, partly cloudy; ●, cloudy; R, rain; K, thunderstorm.

FIG. 94.



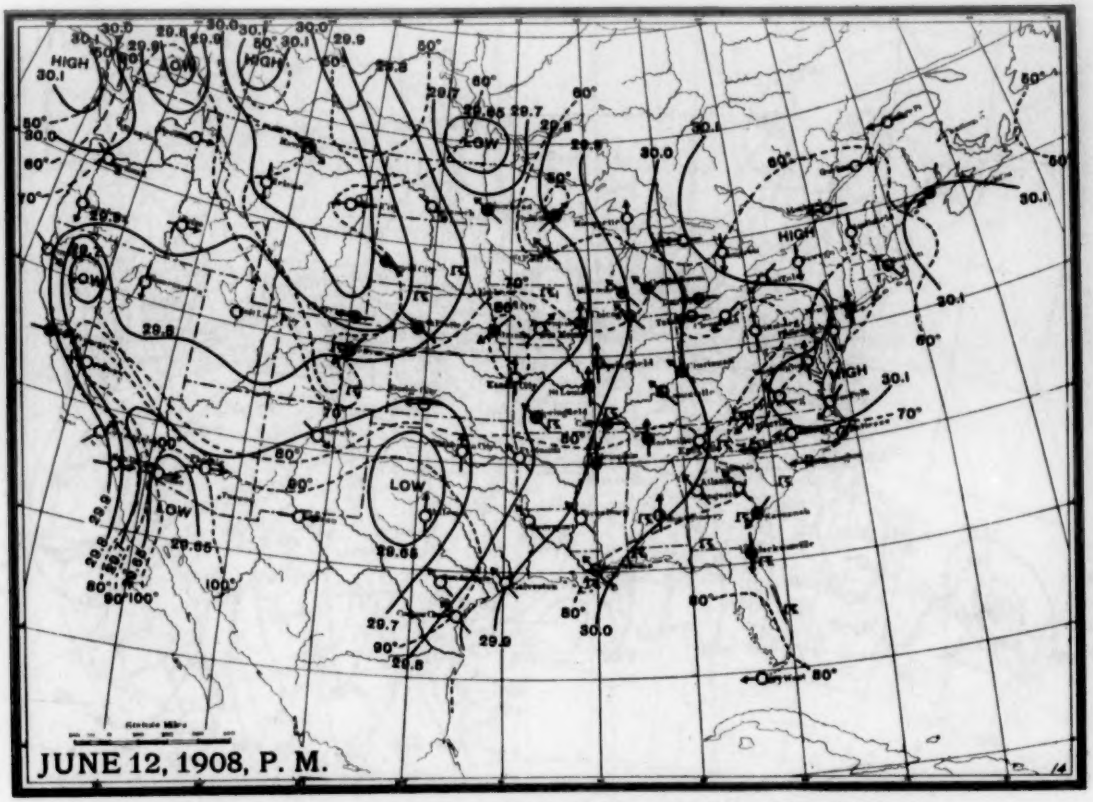
Weather map, 8 P.M., March 1, 1907, typical of "tornadic" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R̄, thunderstorm.

FIG. 95.



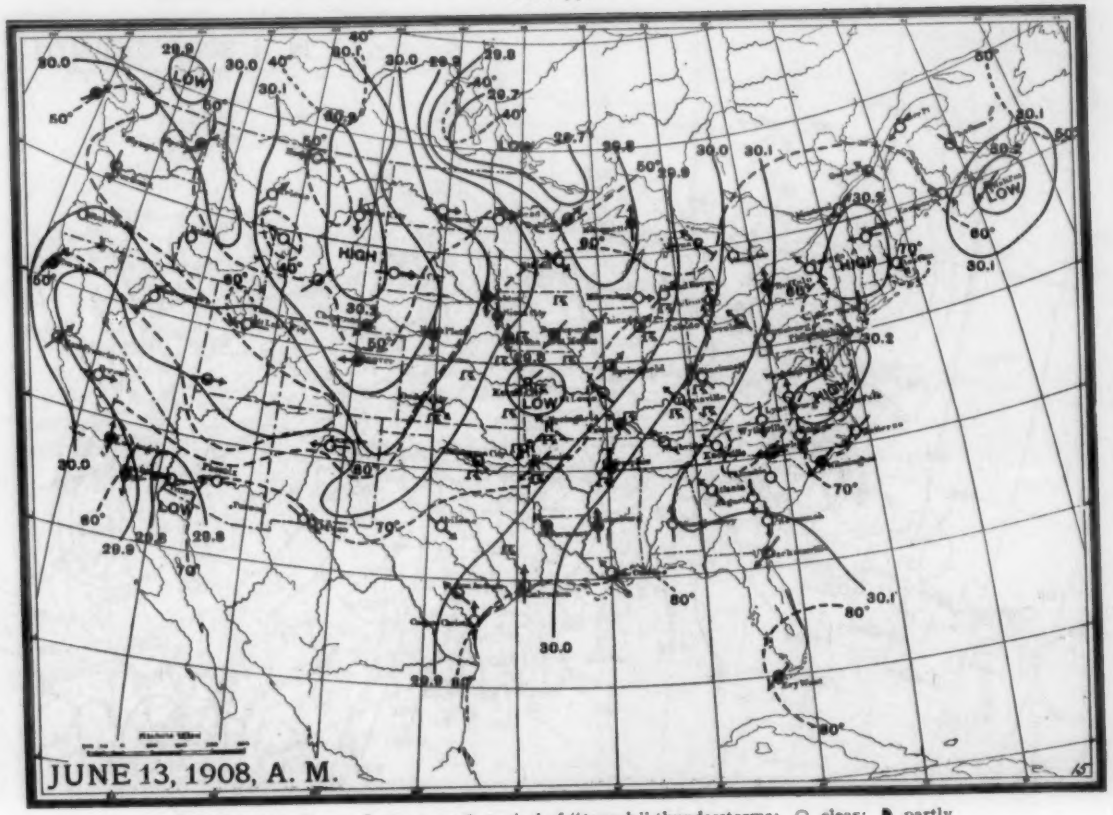
Weather map, 8 A.M., March 2, 1907, typical of conditions at decline of "tornadic" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 96.



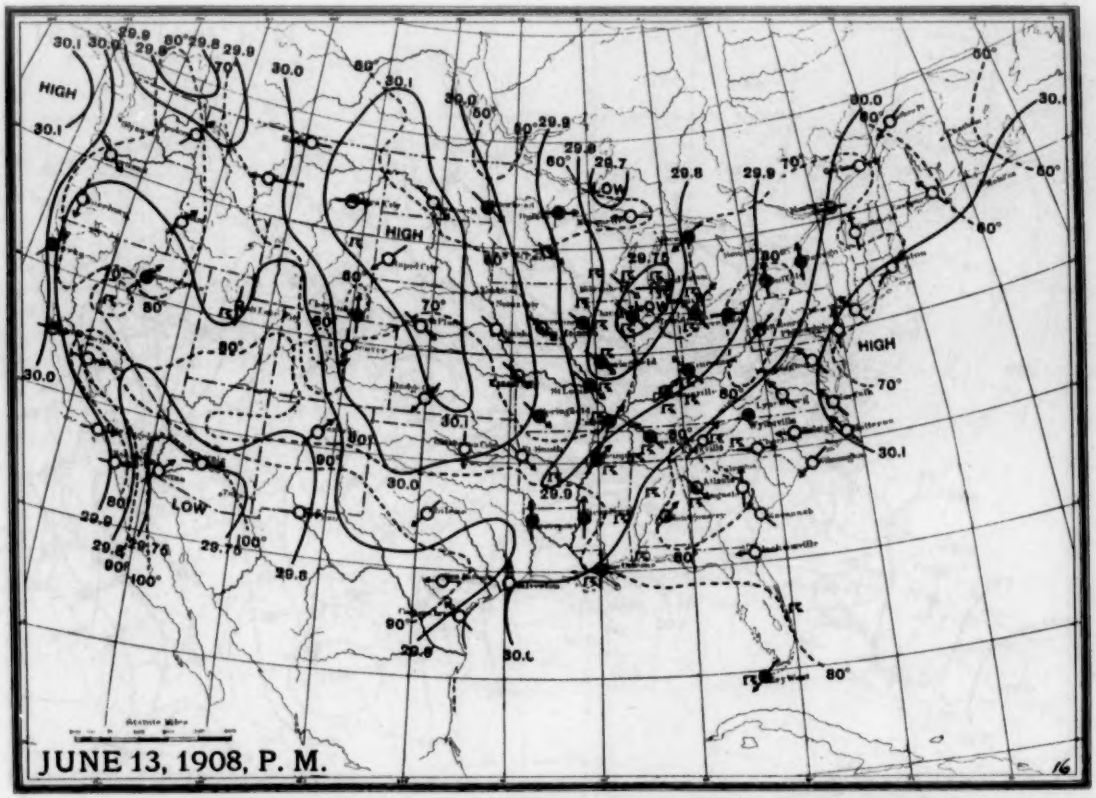
Weather map, 8 P.M., June 12, 1908, typical of conditions at beginning of "trough" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; R, thunderstorm.

FIG. 97.



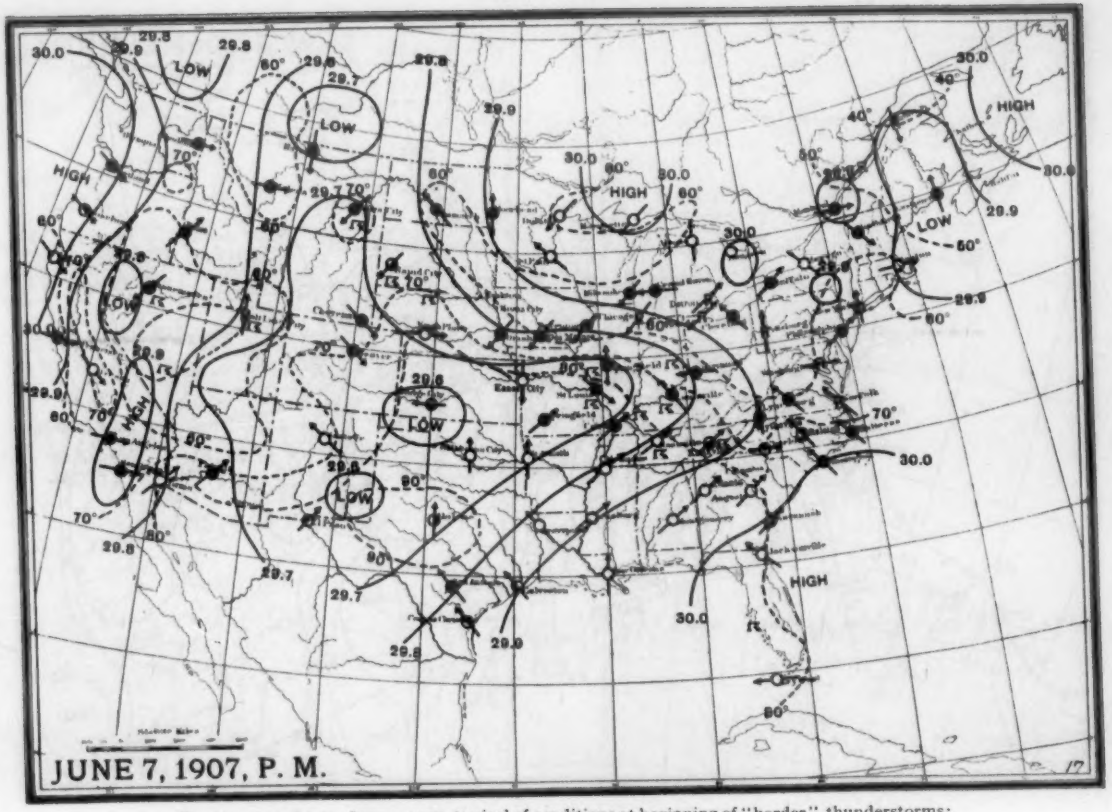
Weather map, 8 A.M., June 13, 1908, typical of "trough" thunderstorms: ○ clear; ◑, partly cloudy; ●, cloudy; R rain; ℞, thunderstorm.

FIG. 98.



Weather map, 8 P.M., June 13, 1908, typical of conditions at decline of "trough" thunderstorms:
○, clear; ◑, partly cloudy; ●, cloudy; R, rain; ℞, thunderstorm.

FIG. 99.



Weather map, 8 P.M., June 7, 1907, typical of conditions at beginning of "border" thunderstorms: ○, clear; ◗, partly cloudy; ●, cloudy; R, rain; R̄, thunderstorm.

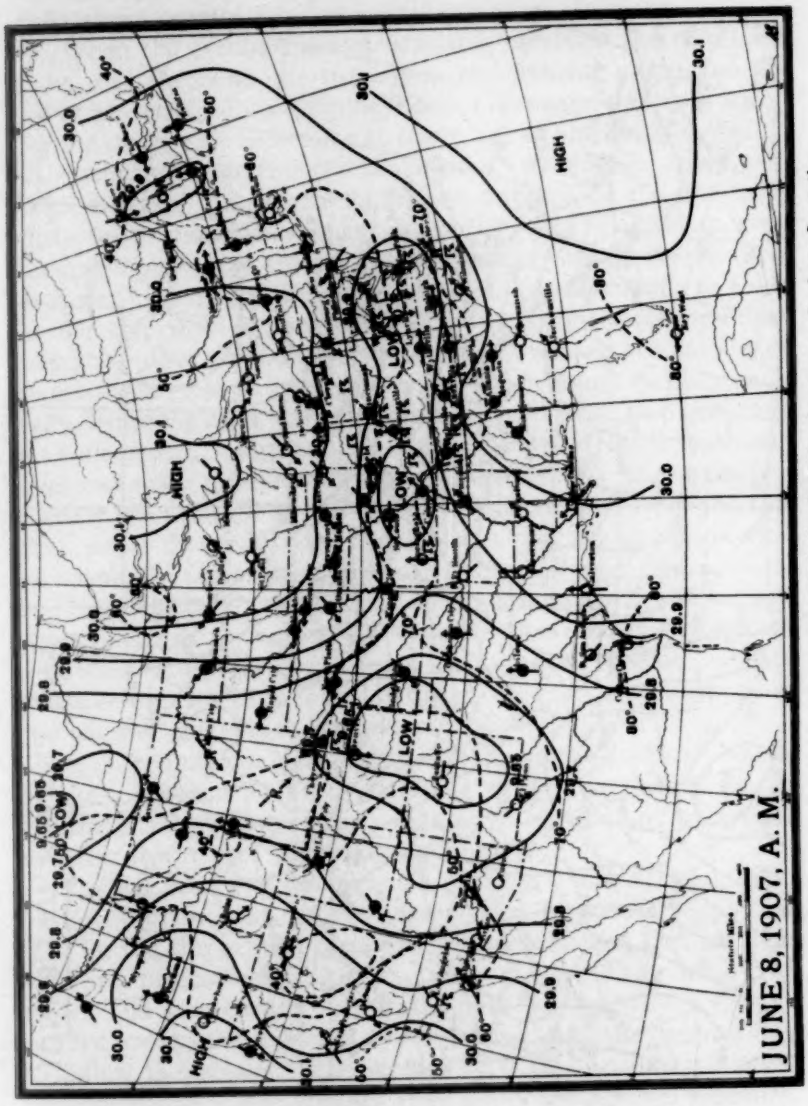
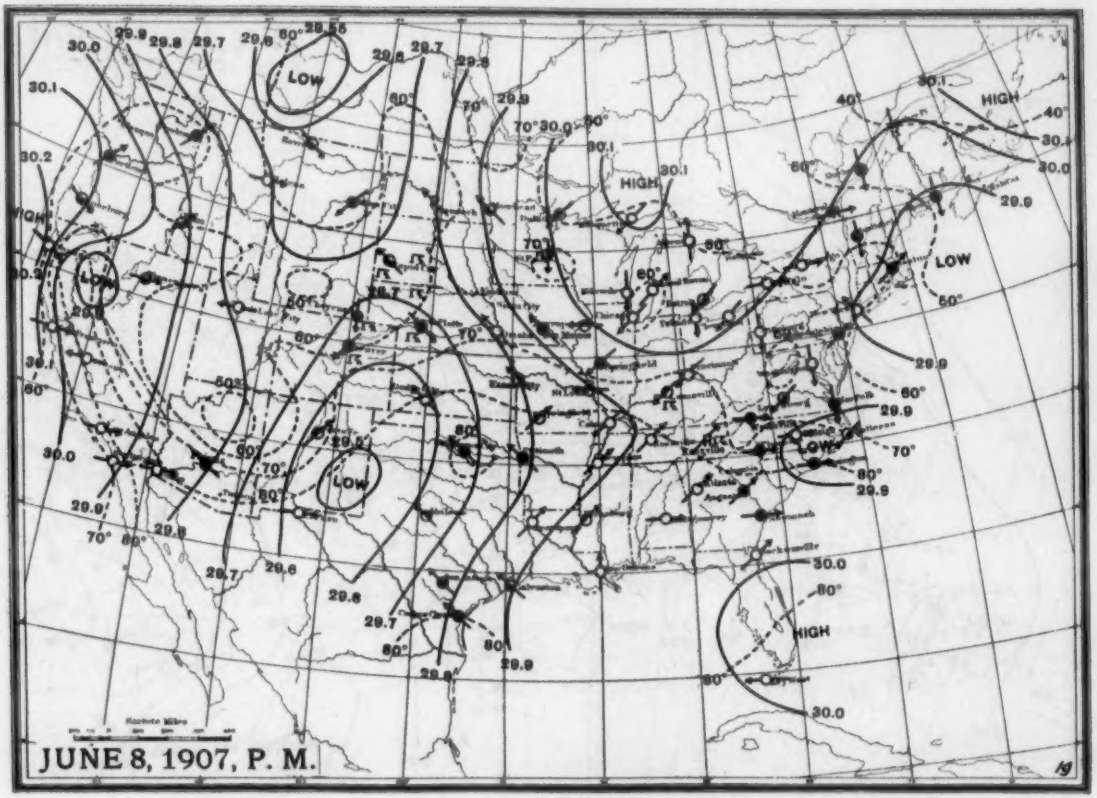


FIG. 100.

Weather map, 8 A.M., June 8, 1907, typical of "border" thunderstorms: ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; K, thunderstorm.

FIG. 101.



Weather map, 8 P.M., June 8, 1907, typical of conditions at decline of "border" thunderstorms; ○, clear; ◑, partly cloudy; ●, cloudy; R, rain; K, thunderstorm.

because of the humidity, slightly below normal or, at most, but little above normal.

When the pressure is approximately uniform the winds are light, and therefore the turbulence and general mixing of the lower air practically negligible, hence every opportunity is given for the surface air to become strongly heated and thereby, finally, to establish vigorous local convections, with their consequent thunderstorms. Such storms, always favored by the drafts up the sides of mountain ranges, and particularly by those up steep mountain peaks and strongly heated valleys, are, of course, most frequent of summer afternoons, and are especially liable to occur at the end of two or three days of unusually warm weather, when the lower air has become so heated that convection extends to relatively great altitudes. They develop here and there sporadically, hence the name "*local*" thunderstorms; last, as a rule, only an hour or two, and travel but a short distance—those that form over mountain peaks often do not travel at all. They also frequently are referred to as "*heat*" thunderstorms, from the fact that, under the given conditions, the necessary initial convection is essentially, if not wholly, due to surface heating.

Local or heat thunderstorms seldom are especially violent and dangerous, and fortunately so, since they are exceedingly numerous, constituting, as they do, well-nigh the only type of thunderstorm in the tropics, and also, perhaps, the most common type in the warmer portions of the temperate zones.

b. The southeast quadrant (northeast, in the Southern Hemisphere), or less frequently, the southwest (northwest, in the Southern Hemisphere), of a regularly formed low, or typical cyclonic storm (see Figs. 90, 91, and 92).

In this case, the temperature gradient essential to a rapid vertical convection is not produced chiefly by surface heating, as it is during the genesis of "*heat*" thunderstorms, but, in great measure, results from the more or less crossed directions of the under- and over-currents of air, the under being directed spirally inward toward the region of lowest pressure and the over tending to follow the isobars. The surface air of the quadrant in question, therefore, normally flows from lower and warmer latitudes, while with increasing altitude the winds come more and more nearly from the west, or even northwest. This crossing of the air currents, then, the lower coming from warmer sections and

the upper from regions not so much warmer—possibly even colder—progressively increases the vertical temperature gradient, or rate of temperature decrease with increase of altitude, and therefore may frequently be, doubtless often finally is, the determining cause of rapid vertical convection and the formation of a thunderstorm.

This particular type of thunderstorm, commonly known as the "*cyclonic*" thunderstorm, is almost wholly confined to the temperate and higher zones, for the simple reason that tropical cyclones, themselves of infrequent occurrence, seldom can have the necessary temperature contrast between its winds of different directions, since all come from equally warm regions. Nevertheless, thunderstorms do occur in connection with many, perhaps nearly all, tropical cyclones. They occur, however, either incidentally during the development of such disturbances or else, later, along their borders and not, or but rarely, within the body of strong winds, and belong, therefore, to the "*heat*" variety rather than to the "*cyclonic.*"

c. The barometric valley between the branches of a distorted or V-shaped cyclonic isobar (see Figs. 93, 94, and 95).

This region is also favorable to the formation of secondary lows, which, though often of small area, sometimes are very intense, even to the genesis of the tornado, the severest of all storms.

Just how specific examples of this type of pressure distribution originated may not always be clear, but, however established, such distribution necessarily leads to opposing surface winds, since these always blow inward at an angle to the isobars, and also to more or less oppositely directed neighboring upper currents, a kilometre or more above the surface, where they tend rather closely to follow the isobars. The winds of each level, the lower and the upper, tend to produce independent effects. Thus the opposing or conflicting surface winds cause such an irregular mixing of the air and such over- and under-running of currents as is likely to establish, here and there, a convection of thunderstorm magnitude. Hence, presumably, the frequency of thunderstorms along the valleys of low-pressure basins. On the other hand, the oppositely directed adjacent, not conflicting, but swift upper currents, on being deflected or drawn together by the convection of the rising current, have their radii of curvature so changed as mechanically to produce, in the middle atmosphere,

violent vortices of limited cross-section, in conformity with the well-known law of the conservation of areas; that is, in conformity with the fact that the angular velocity, or rate of spin, varies inversely with the square of the radius of curvature. The more violent of these vertical atmospheric whirls, accompanied by thunder and rain and often extending down to the surface of the earth, where they become destructive, are known as tornadoes. Hence thunderstorms generated in the barometric region under discussion, the region in which tornadoes most frequently originate and develop, might properly be called "*tornadic*" thunderstorms.

Atmospheric conflicts and turmoil of the nature just described obviously may occur at any place along the protrusion, or valley, of the low-pressure basin, and therefore often do occur, even simultaneously, here and there, along its entire length, and together form the well-known "line squall." Besides, as the whole cyclonic condition moves forward in general from west to east, maintaining, in a measure, for many hours its identity of form and nature, it follows that its valley of low pressure, and therefore its line of thunderstorms, must also travel with it in the same general direction and with approximately the same velocity.

A line or row of thunderstorms—a "line squall"—as observations show, always moves across its own axis, not necessarily at right angles, but nevertheless across and not parallel to it, nor even approximately so. The chief reason for this is not the axial direction of the low-pressure valley, which, indeed, though usually running south, may have any orientation from the parent basin, but rather the fact that the valley itself, together with its accompanying thunderstorm conditions, travels across and not along its own direction.

In this connection it is also worth noting that the temperature distribution in the wake of a thunderstorm renders the occurrence of an immediate successor improbable, as will be explained later. Hence, while a considerable number of thunderstorms may and often do travel abreast, they can never follow each other closely in file.

d. The region covered by a low-pressure trough between adjacent high-pressure areas (Figs. 96, 97, and 98).

Along the adjacent borders of two neighboring anticyclones—that is, along the barometric trough between them—the surface

winds from one side are more or less directly opposed to those of the other, each being directed spirally out from the region of higher pressure. Hence, because of the overrunning, as explained under *c*, and the resulting temperature gradients, this also is a region of frequent thunderstorms. Here, too, a number of more or less independent storms may exist simultaneously along the same line, and advance abreast for considerable distances across the country.

There does not appear to be any independent or distinctive name for the thunderstorm generated under this type of pressure distribution. Perhaps it might, with some justification, be called the "*anticyclonic*" thunderstorm, or even the "trough" storm.

e. The boundary between warm and cold waves (see Figs. 99, 100, and 101).

Along such a boundary the direction of flow of the warm, humid layers of air is more or less opposite, as shown on the maps, to that of the colder ones. Therefore it must frequently happen that at irregular intervals along such a boundary upper air coming from the cold area overruns a section of surface air belonging to the warm region. Now, wherever this overrunning on the part of the cold air does occur the vertical temperature gradient is likely to be abruptly and greatly increased, and wherever, as a result of either the initial overflow or of further movement, the new gradient exceeds the adiabatic rate of temperature change, as, analogous to case *b*, it often must, under the given conditions, vertical convection, with rain, thunder, and lightning, is apt to occur. Hence, as stated, the boundary between warm and cold waves is another place favorable to the genesis of the thunderstorm. Here, too, as in cases *c* and *d* above, a characteristic name is lacking. Possibly with reference to its place of occurrence—that is, along the boundary between warm and cold waves—one might call it the "border" storm.

The above five types of weather conditions, together with their innumerable variations and combinations, probably include all that are distinctly favorable to the development of thunderstorms. Each tends to establish an adiabatic, or even superadiabatic, temperature gradient up to the cloud level, the one thing essential to the production of strong vertical convection, the progenitor, as we have seen, of the thunderstorm.

(*To be continued.*)

PERMANENCE IN PHOTOGRAPHIC PRINTS.

BY

HENRY LEFFMANN,

Member of the Institute.

IN the current number of the JOURNAL of the Institute (May, 1918) a short abstract is given from the *British Journal of Photography,* concerning methods of producing permanent photographic prints. The matter is of great importance, nowadays, because the application of photography to the copying of written and printed records is rapidly displacing the old method of transcription. The general features of the method were presented by me in a paper read before the Photographic Section of the Institute in October, 1901, and published in the JOURNAL a month later. I there showed the great advantage that would accrue if the ordinary municipal records, such as deeds, mortgages, and wills, were copied by photography instead of the present tedious and fallible methods of transcription. Not the least advantage of the photographic method is that the signatures, erasures, corrections, spelling, and punctuation are faithfully reproduced.

The *British Journal* article speaks of a guarantee of permanency for about a quarter of a century, but this is far short of what official business will require. The processes mentioned are platinum, carbon and silver bromide. Under existing conditions, platinum should not be allowed for use in photography. The carbon print is unfading, whether produced in the earlier forms or by the later and now much used " gum-bichromate " method. It is notable that the *British Journal* does not refer to the blue-print. This seems to be as permanent as any. It is inexpensive, simple in manipulation, and reproduces distinctly the finest detail. When I prepared the paper noted above, I inquired of a railroad engineer as to the durability of blue-prints, and he told me that his company had in its vaults prints at least twenty-five years old, which, so far as could be judged by inspection, were as vivid as the day they were made. I think, therefore, that in this matter the blue-print should be given a full investigation.

A very important feature of this question is the quality of the paper. It is likely that more failures in permanency will obtain from bad paper than from a bad process. Methods of testing paper are now so highly developed that it will be quite easy to establish specifications which will give a paper at reasonable price that will last for centuries. It should be free from chemicals that may react with the deposit that forms the print.

It is greatly to be regretted that the record offices of our municipal, state and national governments have not adopted extensively the photographic methods of copying. Such methods are more rapid and cheaper than the transcription, even when typewriting machines are employed, while of course as far as regards accuracy, even to the minutest detail, the best transcription cannot compare with the photograph.

Proposed Ramsay Memorial Fund. C. BASKERVILLE. (Communication, The College of the City of New York.)—After the death of Sir William Ramsay, in July, 1916, a memorial meeting was held in London to commemorate his thirty-five years of service in physical and chemical sciences, education, and public welfare. This gathering of distinguished men, under the chairmanship of Lord Rayleigh, decided to raise a substantial fund as a memorial to be used in the establishment of Ramsay Research Fellowships, tenable wherever necessary facilities might be available, and a Ramsay Memorial Laboratory of Engineering Chemistry at the University of London, where he served twenty-six of his most fruitful years of activity.

A committee of men, prominent in the physical and chemical sciences in Great Britain, including the leaders of the Coalition Government and Ambassadors then accredited to the Court of St. James, was later organized. Through this general organization committees were appointed and correspondence to that end carried on throughout the civilized world. The sum set out to be raised was £100,000. To date something over £300 have already been contributed by residents of the United States. The committee expects some generous contributions, but it hopes especially to have a great number of small subscribers. The receipt of contributions for one dollar or over, sent to the Ramsay Memorial Fund Association, 50 East Forty-first Street, New York City, will be promptly acknowledged.

A more suitable memorial of the epoch-making work of this noted investigator could scarcely be devised. By such a foundation a real and, at this time, thoroughly appreciated need will be served.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

COMPARATIVE TESTS OF CHEMICAL GLASSWARE.[1]

By Percy H. Walker and F. W. Smither.

[ABSTRACT.]

BEAKERS of Kavalier glass, and beakers and flasks of Macbeth Evans Glass Co., Pyrex, Jena, Nonsol, Fry and Libbey glasses were tested for chemical composition, coefficient of expansion, refractive index, strain, behavior on repeated evaporation, resistance to heat and mechanical shock, and to solution in a variety of chemical reagents.

No conclusions as to the relative values of the different wares can be drawn from the chemical analyses, though these analyses may be useful by enabling the chemist to choose a glass which will yield no objectionable ingredient to the solutions used in any particular piece of work. The coefficient of expansion of all the glasses is low and is unusually so in Pyrex ware. All the ware shows more or less strain, but it was disappointing to find that no information as to liability to break under sudden changes in temperature or mechanical shock could be obtained by an examination for strain. All the ware tested showed good resistance to repeated evaporation of a salt solution. While the heat and mechanical shock tests were performed on too small a number of pieces to justify positive conclusions, they indicated that the Kavalier and M. E. G. Co. ware are less resistant than Jena, Nonsol, and Fry wares, the Libbey somewhat more resistant and the Pyrex ware distinctly more resistant. The Kavalier ware is unsatisfactory as regards solubility in water; all the other wares appear satisfactory in this respect. All the ware is resistant to acids, Kavalier is least resistant to carbonated alkalies, Pyrex more resistant than Kavalier but less resistant than the others. Kavalier and M. E. G. Co. wares are more resistant to boiling caustic alkaline solutions than the others but the differences are not great. All the glasses are much attacked by evaporating caustic alkalies. Ammonia water has about the same effect as mixtures of ammonium chloride and sulphide. The authors are of the opinion that considering all the tests each of the American wares is superior to the Kavalier and equal or superior to the Jena ware.

* Communicated by the Director.

[1] Technologic Papers of the Bureau of Standards, No. 107.

Antifreezing Solutions for Automobile Radiators. ANON. (U. S. Bureau of Standards, Department of Commerce, Washington, D. C., March 20, 1918.)—The ideal antifreezing compound is one that will prevent freezing of the radiator liquid without injuring either engine or radiator, that will not lose its non-freezing properties after continued use, and that does not materially change the boiling-point of water when dissolved in it. There are two general types of these compounds; one a solution in water of alcohol or glycerin, or a mixture of the latter two; the other, a solution in water of calcium chloride or the dry salt itself, which contains sometimes small amounts of other substances, such as salt, sal ammoniac, sugar, or syrup. Kerosene and similar oils, without admixture, are sometimes used.

Kerosene has a lower freezing-point and higher boiling-point than water, but the inflammability of its vapor makes it dangerous to use, and its high and uncertain boiling-point might lead to the serious overheating of the engine, or even to the melting of the solder in the radiator. Its marked solvent action on rubber parts is also an objection to its use. The alcohol-water type is the most common and is not generally sold under any trade name, but recently there have appeared on the market a number of antifreezing compounds of the calcium chloride type. These compounds are sold under a variety of names, and startling claims are made for their effectiveness and lack of injurious effects.

The alcohol solutions do not exert a greater corrosive action than water alone. This can be predicted from theoretical considerations and is well established in practice. However, wood alcohol sometimes contains free acid, such as acetic acid, which is objectionable, and for that reason wood alcohol should be used only when it is known to be free from acids. The calcium chloride compounds exert a greater corrosive action than water on the engine jacket, on the solder in the radiator, and on aluminum, which is sometimes used in manifolds, pumps, and headers. Another troublesome effect of calcium chloride solutions is experienced if small leaks occur in the radiator, the water jackets, or connections, and the solution comes in contact with the spark-plugs and ignition wires. In some cases the drops of the solution may be carried back on the engine in a more or less atomized state, assisted by the fan when running. The salt deposited when the water evaporates is very difficult to remove, and when it cools absorbs water and becomes a good electrical conductor, short-circuiting the spark-plugs and sometimes making it impossible to start the engine. The difficulty may disappear when the engine is heated up. There are also certain conditions in the manufacture of calcium chloride which may result in a compound that will deposit large crystals in the radiator as the solution cools; this may prevent effective circulation.

NOTES FROM NELA RESEARCH LABORATORY.*

THE VISIBILITY OF RADIATION.

By Edward P. Hyde, W. E. Forsythe and F. E. Cady.

In connection with an investigation of the brightness of a black body at various temperatures, it was desired to check the observations against values derived by computation, using the Planck energy equation and visibility data. As the only recent experiments on the latter have all been made by the use of the flicker photometer and as there is evidence that results by this method are at variance with those obtained by the method of direct comparison ordinarily used in photometry, possibly because of inherent differences and possibly due to conditions imposed in the flicker method such as restricted field size, it seemed desirable to obtain new data on the visibility function by the direct comparison method under conditions comparable with those obtaining in the black-body brightness determinations referred to above.

The distinguishing characteristics of the investigation, apart from the employment of the direct-comparison principle and from the conditions with respect to field size, etc., used in ordinary photometric practice, are the use of the step-by-step method and the determination of the energy distribution in the spectrum. The steps chosen were so small (0.0052 μ in the red to 0.0022 μ in the blue) that the hue difference while appreciable, did not cause any decided difficulties in making the settings. The energy was evaluated by determining the color temperature of the source, and computing the distribution by means of Planck's equation, allowing for dispersion and absorption by the optical system, and for scattered light. In this way the relative energy entering the eye in the different parts of the spectrum was readily determined.

The apparatus employed consisted in an ordinary Lummer and Brodhun spectrophotometer provided with a special slit which could be moved a definite fixed amount, 0.15 mm., in order to

* Communicated by the Director.

provide the means for the shift of one spectrum with respect to the other, this procedure being required to carry out the step-by-step method. As a source a flat filament tungsten lamp was used, operating at a color temperature approximately 2045° K. Measurements were made by 29 observers and the 29 luminosity curves obtained, after reducing them to the same area, were averaged at each wave-length. The results are given in Column 2 of Table I. The relative average visibility data were reduced on the basis of equal areas of the luminosity curves for the chosen color temperature (approximately 2045° K.). The results of other recent investigators are also included.

TABLE I.

Data on Relative Visibility.

Wave-Length.	Hyde Forsythe Cady.	Ives Kingsbury.	Nutting.	Coblentz Emerson.	Reeves.
0.50μ	0.328	0.318	*0.314	0.316	0.275
.51	.515	.473	.456	.503	.474
.52	.698	.637	.646	.710	.686
.53	.847	.801	.815	.862	.841
.54	.968	.915	.925	.954	.935
.55	.996	.988	.986	.994	.993
.56	.995	.996	.995	.998	.985
.57	.944	.947	.949	.968	935
.58	.855	.859	.871	.898	.836
.59	.735	.758	.762	.800	.710
.60	.600	.653	.634	.687	.580
.61	.464	.534	.498	.557	.446
.62	.341	.396	.368	.427	.319
.63	.238	.283	.268	.302	.214
.64	.154	.183	.166	.194	.140
.65	.095	.110	.105	.115	
.66	.052	.068	.058	.064$_5$	

*Revised values kindly furnished by Doctor Nutting.

In addition to the investigation just described a supplementary investigation of the relative visibility was made, using the same spectral pyrometer and method as previously used for studying this function in the red and blue ends of the spectrum.[1] Ten out of the twenty-nine observers participated, and the results form a curve somewhat flatter near the centre and dropping off more rapidly towards the two ends of the spectrum. The previously

[1] *Astrophys. Jour.*, **42**, p. 285, 1915.
Phys. Rev. (2) **11**, p. 327, 1918.

obtained data in the red and blue ends of the spectrum fit nicely on the ends of this curve. In Table II are given data recommended by the authors on relative visibility covering practically the entire visible spectrum. The values from 0.50 μ to 0.64 μ are those given in Column 2 of Table I. For the red end are chosen the previously published data of Hyde and Forsythe brought into agreement with the central region of the curve at 0.64 μ. For the blue end the published data of Hartman have been chosen as the best.

TABLE II.

Relative Visibility Data for Entire Spectrum.

Wave-Length.	Relative Visibility.	Wave Length.	Relative Visibility.	Wave-Length.	Relative Visibility.
0.40μ	0.00009	0.52μ	0.698	0.64μ	0.154
.41	$.0006_2$	.53	.847	.65	.094
.42	$.004_1$	.54	.968	.66	.051
.43	$.011_8$	.55	.996	.67	.026
.44	.022	.56	.995	.68	$.012_5$
.45	.036	.57	.944	.69	$.006_2$
.46	.055	.58	.855	.70	$.003_1$
.47	.087	.59	.735	.71	$.001_5$
.48	.138	.60	.600	.72	$.0007_4$
.49	.216	.61	.464	.73	$.0003_6$
.50	.328	.62	.341	.74	$.0001_8$
.51	.515	.63	.238	.75	.00009
				.76	.00005

NELA RESEARCH LABORATORY,
National Lamp Works of General Electric Company,
Nela Park, Cleveland, Ohio, May, 1918.

The Action of Bleaching Agents in Fibres. J. M. MATTHEWS. (*Color Trade Journal*, through *Paper*, vol. 21, p. 13, November 28, 1917).—Bleaching in its general sense may be considered as a decoloration, or, more properly speaking, a destruction of the natural coloring matter which may be present in the substance under treatment. This is in contradistinction to the term "stripping," which is used in cases where the color from a dyed material is removed. All of the textile fibres, whether of animal or vegetable origin, possess more or less coloring matter or pigment in their composition. Wool, for instance, with its congener hair is known to exist in a number of colors, varying from a pale yellow to a deep brown or black. Even ordinary "white" wool has a slightly yellowish cast on scouring-out, due to the presence of a natural organic pigment in the fibre. In the large majority of cases the presence of natural coloring matter in the fibre is not appreciably detrimental to the color to be produced by

the dyestuffs. When delicate shades and tints, however, are desired, or when it is required that the fibre be left undyed in a white condition, it generally becomes necessary to remove the natural coloring matter from the fibre by some suitable chemical treatment. The process by which this is accomplished is termed "bleaching," a word signifying "to whiten."

The destruction or removal of the natural coloring matter in the textile fibres may be brought about by a variety of methods. In certain cases it is only necessary to tint the material with a complementary color to that already present, and, as this latter is usually a yellowish or a yellowish-brown tint, the complementary tint combines with the natural color, producing a neutral gray tone. As the eye is far less sensitive to this character of tint than it is to either of the complementary or component tints, the material appears, in consequence, to have much less color, or, in other words, appears whiter. In this tinting method of bleaching there is no actual destruction of the natural coloring matter present, and there is in reality more color in the fibre after tinting than before, only it is not so apparent to the eye. A very familiar example of this method of bleaching or whitening is the so-called "bluing" in the ordinary home wash or in the laundry.

The coloring matters existing in the raw textile fibres are of organic nature; that is to say, they are of animal or vegetable origin, not mineral compounds. Being of this nature, they are peculiarly susceptible to the action of various chemical agents, both of a reducing and oxidizing character.

It is on these facts that the two processes of bleaching at present in vogue depend for their efficiency. The one which is used almost exclusively in connection with the animal fibres involves the use of a strong reducing agent, such as sulphurous acid, sodium hydrosulphite, etc. The other process employs a strong oxidizing agent, such as hydrochlorous acid (or its salts), which finds its use in connection with the vegetable fibres, or hydrogen peroxide, which may be employed in connection with all fibres.

Other processes of bleaching have been introduced from time to time, some of which depend upon the electric current, like the so-called electrolytic method. This method is carried out by means of a solution of sodium hypochlorite, a current of electricity being passed through a solution of common salt (sodium chloride) whereby sodium hypochlorite is formed, and this serves as the bleaching agent. The hypochlorite is also prepared from liquid chlorine by dissolving the gas in a suitable alkali, such as a solution of soda ash or caustic soda. A more direct use of electricity has been suggested as a means of rendering chlorine gas (in the presence of moisture) more effective in its bleaching qualities; the gas being conducted through an apparatus provided with two electrodes between which electric sparks are continually passing. Ozone has also been employed as an oxidizing bleaching agent, but the high cost of its production makes it almost prohibitive for general use.

THE FRANKLIN INSTITUTE.

(*Proceedings of the Stated Meeting held Wednesday, May 15, 1918.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, May 15, 1918.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 1.

The Chairman announced that the business of the meeting would be the annual presentation of the Franklin Medal, the Institute's highest award, in recognition of distinguished scientific and technical achievements, and called upon Dr. Harry F. Keller, who gave an account of the work of Signor Guglielmo Marconi, of Bologna, Italy, recently recommended by the Institute's Committee on Science and the Arts for the Franklin Medal in recognition of "His brilliant inception and successful development of the application of magneto-electric waves to the transmission of signals and telegrams without the use of metallic conductors."

Doctor Keller then presented His Excellency, Count V. Macchi de Cellere, Ambassador of the Royal Italian Government to the United States, who received the medal for Signor Marconi, and conveyed the thanks of his Government and of the recipient for the honor conferred upon him.

Doctor Keller then introduced Thomas Corwin Mendenhall, Sc. D., LL.D., of Ravenna, Ohio, who had also been recommended for the award of the Franklin Medal in recognition of "His fruitful and indefatigable labors in physical research, particularly his contributions to our knowledge of physical constants and electrical standards."

The Chairman presented the medal to Doctor Mendenhall, who expressed his thanks for the honor conferred upon him, and then read his paper, "Some Metrological Memories." He outlined the progress made in electricity during the last fifty years. Reference was also made to the International Electrical Exhibition of 1884, held under the auspices of The Franklin Institute, and the work accomplished by the International Electrical Conference held in Philadelphia in the same year. An account was given of the efforts to establish a system of electrical units, the adoption of the definitions for the principal practical units by the International Electrical Congress of 1893, and the legalization of these by Congress. The speaker expressed the opinion that metrology is the mother of science and of art, certainly of all the exact sciences and of nearly all of the arts, and that without it there could be no astronomy, no physics, no chemistry, no engineering, no architecture.

At the close of the address the thanks of the meeting were extended to the guests.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

(A full account of the meeting will appear in the next issue.)

MEMBERS OF THE FRANKLIN INSTITUTE WHO ARE IN THE ACTIVE MILITARY OR NAVAL SERVICE OF THE UNITED STATES GOVERNMENT.

Name and rank	Branch of service	Location
Abbott, A. C., Lieut.-Col.	Greenleaf School of Military Hygiene	Chickamauga Park, Ga.
Allen, Henry B., 1st Lieut.	Ordnance Dept., U. S. R.	France
Anderson, Geo. L., Colonel	Board of Ordnance & Fortification	Washington
Atherholt, Gordon Meade	Aeronautical Mechanical Engineer, Signal Corps	Washington
Atterbury, W. W., Brig. Gen.	Director-General of Railways	France
Bacon, Raymond Foss, Lt. Col.	Head of Chemical Service Section, U.S.N.A.	France
Barnhart, G. Edw.	Aeronautical Mechanical Engineer, Signal Corps	Fairfield, Ohio
Barr, John H., Major	Ordnance Reserve Corps	Washington
Barrett, C. D., Major	9th Engineers	
Bartow, Edward, Major	U.S.N.A. Sanitary Corps	France
Booz, Horace Corey, Colonel	Railroad Transportation Corps, U.S.N.A.	France
Bostwick, John Vaughan, Capt.	O.R.C., 315th Infantry	Camp Meade
Breed, George, Lieutenant	Fleet Naval Reserve, U.S.N. R.F.	New York
Bunting, C. M., Colonel	E.O.R.C., U.S.A.	France
Cadwalader, Governeur, Major	Ordnance Dept., U.S.R.	
Caldwell, E. W.	Medical Officers' Reserve Corps	
Capps, W. L., Rear Admiral	Chief Constructor, U.S.N., Bureau of Construction and Repair	Washington
Carty, John J., Colonel	Signal Corps, U.S.A.	
Chance, Edwin M., Capt.	Ordnance Dept., U.S.R.	Washington
Clark, Beauvais, Sergeant	108th Field Artillery	Camp Hancock
Clark, E. L., 1st Lieut.	Signal Corps, 401st Telegraph Battalion	Camp Devens
Clark, Theobald F., Capt.	Field Artillery	
Clark, Walton, Jr., Capt.	Field Artillery	
Cornelius, John C., 1st Lieut.	Coast Artillery, U.S.N.A., 13th Company	Sandy Hook
Cottrell, Jas. W., Private	Instruction Section, Ordnance Dept., U.S.A.	Peoria, Ill.
Cowan, Henry B., Sergeant 1st Class	Co. D., First Telegraph Battalion, Signal Reserve Corps	France
Crampton, George S., Major	Director of Field Hospitals, 28th Div.	Camp Hancock
Cushman, A. S., Lieut. Col.	Ordnance Dept., U.S.N.A.	Frankford Arsenal
Detwiler, Jas. G., 1st Lieut.	Infantry, U.S.R.	Fort Logan H. Roots
Eckert, S. B., Lieut.	Commander 9th Aero Squadron	France
Elliott, Henry M., 1st Lieut.	Ordnance Dept., U.S.R.	Western Cartridge Co.
Emerson, Geo. H., Colonel	In charge of Russian Railway Service Corps	Japan
Felton, Samuel M.	U. S. Director-General of Railways in connection with Expeditionary Force	Chicago

Name and rank	Branch of service	Location
Ferguson, Walter B., Private	21st Co., 154th Depot Brigade	Camp Meade
Fraser, Persifor, Ensign	U.S.N.R.F.	League Island
Gardner, H. A., Senior Lieut.	Naval Flying Corps	Washington
Gfrörer, A. H., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Gibbons, Joseph E., Private	Co. D., 103rd Engineers	Camp Hancock
Gilbreth, Frank B., Major	Engineers O. R. C.	Washington
Gillmor, R. E., Senior Lieut.	U. S. Navy	New York
Glendinning, Robt. E., Major	Aviation Section, Signal Corps	Overseas
Goodwin, Harold, Jr., Lieut.	Naval Reserve Force	Philadelphia
Gribbel, W. G., Captain	Co. A., 30th Engineers, U.S.R. (Gas and Flame)	France
Griest, Thos. S., 1st Lieut.	1st Telegraph Battalion, Signal Corps, U.S.A.	France
Hall, R. T., Rear Admiral	U. S. Navy, Inspector of Machinery	Cramps' Shipyard
Hodges, Austin L., Capt.	Ordnance Dept., U.S.R., Experimental Officer on Artillery Ammunition	Frankford Arsenal
Howson, Richard, Sergeant	306th Ambulance Corps	Camp Meade
Ives, H. E., Captain	Signal Corps, U.S.A.	Washington
Jackson, John Price, Major		France
Jones, Jonathan, Captain	E.O.R.C., 23rd Engineers	Camp Laurel
Karrer, Enoch, Sergeant	45th Engineers, Company A	Camp A. A. Humphreys
Kennedy, M. C., Colonel	Deputy Director General of Transportation	France
Kent, S. Leonard, Jr., 2nd Lieut.	5th Engineers	Camp Lee
Kingsbury, E. F., 1st Lieut.	Aviation Section, S.O.R.C., Dept. of Science and Research	Washington
LeBoutillier, H. W., Private	Unit No. 10, Pennsylvania Hospital	France
Lichtenberg, Chester, 1st Lieut.	Engineer Reserve Corps, U.S.A.	Washington
Longstreth, Chas., Lt. Commander	U.S.N.R.F.	Philadelphia
McCoy, John F.	Aviation Section, Signal Corps	Princeton
MacLean, Malcolm R., Major	Infantry R. C.	Camp Meade
McMeekin, C. W., Major	Army War College	Washington
Martin, Thos. S., 1st Lieut.	Ordnance Dept., U.S.R.	Washington
Masters, Frank M., Major	Ordnance Dept., U.S.R.	Washington
Maxfield, H. H., Lieut. Col.	19th Railway Engineers, U.S.N.A.	
Mershon, Ralph D., Major	E.O.R.C., U.S.A.	New York
Miller, Fred. J., Major	Ordnance Reserve Corps	Centre Bridge, Penna.
Owens, R. B., Major	Signal Corps	France
Parrish, T. R., Captain	Signal Corps	Washington
Reber, Samuel, Colonel	Signal Corps, U.S.A.	New York
Richardson, Chas. E., 1st Lieut.	30th Engineers, U.S.R. (Gas and Flame)	France
Spackman, Henry S., Major	Engineer Officers' Reserve Corps	France
Spruance, W. C., Jr., Lt. Col.	Ordnance Dept., National Army	Chevy Chase, Md.
Squier, Geo. O., Major General	Chief Signal Officer, U.S.A.	
Stanford, H. R., Civil Engineer	U. S. Navy	Boston
Thomas, Geo. C., Jr., Captain	Aero Service Squadron 96, Aviation Section, Signal Corps	France
Tilghman, B. C., Captain	A.D.C., 28th Div. Headquarters, U.S.A.	

Name and rank	Branch of service	Location
Vogleson, J. A., Major		Camp Jas. E. Johnston
Wagner, Fred. H., Major	Ordnance Reserve Corps, Nitrate Division	Washington
Wagner, Fred. H., Jr. Sergeant	Co. E., 304th Engineers	Camp Meade
Wells, G. A., Captain	Ordnance Reserve Corps	Peoria, Ill.
Wetherill, W. C., Ensign	U. S. Navy	
Widdicombe, R. A., Major	C.Q.M., Chemical Plant No. 4	Saltville, Va.
Wood, Edw. R., Jr., Captain	18th Field Artillery, U.S.N.A.	El Paso, Texas
Worrell, Howard Sellers	3rd Officers' Training Camp	Fortress Monroe
Wyckoff, A. B., Lieut.	U. S. Navy	Ontario, Cal.
Yale, A. W. Major	Medical Reserve Corps, Gas Division	Camp Kearney
Yorke, George M., Major	Signal Corps, U.S.R.	New York

MEMBERS DOING CIVILIAN WORK FOR THE UNITED STATES GOVERNMENT

Name	Appointment	Location
Akeley, Carl E.	Consulting Expert of Mechanical Devices, War Department	Washington
Anderson, Robt. J.	Engineer of Tests of Ordnance, War Dept., U.S.A.	Brier Hill Steel Co.
Balls, William H.	Ships Draughtsman	Phila. Navy Yard
Bancroft, Joseph	Secretary, Local Board No. 1	Wilmington
Baskerville, Charles	Working with Bureau of Mines, Ordnance Dept. (Gas Warfare, Shells, etc.)	New York
Bodine, Samuel T.	Vice-Chairman, District Exemption Board, No. 1, Eastern Judicial District of Penna.	Philadelphia
Brown, Lucius P.	Federal Milk Commission	New York
Burnham, George, Jr.	Dept. of Civilian Service and Relief, Public Safety Committee of Pennsylvania	Philadelphia
Charles, Bernard S.	Ordnance Inspector, U. S. Navy	Allentown, Pa.
Comey, Arthur M.	Chairman, Sub-Committee on Explosives, Chemistry Committee, National Research Council	Chester, Pa.
Condict, G. Herbert	Naval Consulting Board, Member Committee of Examiners	Plainfield, N. J.
Cooke, Morris L.	Chairman, Storage Committee of Munitions Board; Member on Staff, Emergency Fleet Corporation	Washington
Cope, Thomas D.	National Research Council	Washington
Day, Charles	Member of Army War Council	Washington
Delano, Frederic A.	Member of Federal Reserve Board	Washington
Dickie, G. W.	Chief Inspector, U. S. Shipping Board, Moore & Scott Shipyard	Oakland, Calif.
Dunn, Gano	Chairman, Engineering Committee, National Research Council	New York
Garrison, Frank Lynwood	Chairman, U. S. Manganese Commission	Philadelphia
Halberstadt, Baird	Federal Fuel Administrator for Schuylkill Co., Penna.	Pottsville

Name	Appointment	Location
Hoskins, Wm.	Consulting Chemist, Advisory Committee, Bureau of Mines; Associate Member, Naval Consulting Board	Chicago
Hyde, Edward P.	National Research Council, Sub-Committee on Monocular vs. Binocular Field-Glasses (Chairman).	Cleveland
Insull, Samuel	Chairman, Illinois State Council of Defense	Chicago
Kennelly, A. E.	Conducting special course in radio-engineering for the U. S. Signal Corps, in conjunction with Prof. E. C. Chaffee	Harvard Univ.
Lloyd, E. W.	Asst. Secretary, Illinois State Council of Defense	Chicago
Lucke, C. E.	Civilian Director, U. S. Navy Gas Engine School	Columbia Univ.
Merrick, J. Hartley	Director, Bureau of Camp Service, Penna. Div., American Red Cross	Philadelphia
Milne, David	Treasurer, American Red Cross General Hospital No. 1	Philadelphia
Morris, Effingham B.	Treasurer, Committee of Public Safety, State of Pennsylvania	Philadelphia
Nichols, Carroll, B.	Fuel Administration	Washington
Nichols, Wm. H.	Committee on Chemicals, Advisory Council of National Defense, Consulting Chemist, Bureau of Mines	New York
Penrose, R. A. F., Jr.	Member of Geology Committee of the National Research Council	Philadelphia
Rapp, Isaiah M.	Special Investigator of Weights and Measures for the U. S. Food Administration	Norman, Oklahoma
Rautenstrauch, Walter	Committee of the National Research Council	New York
Richards, Joseph W.	Member of Naval Consulting Board	So. Bethlehem, Penna.
Robins, Thomas	Member and Secretary of the Naval Consulting Board	New York
Sperry, Elmer A.	Member of Naval Consulting Board	Brooklyn, N.Y.
Sprague, Frank J.	Member of Naval Consulting Board, Chairman, Committee on Electricity and Shipbuilding	
Stern, Max J.	Supervising Surgeon, Merchant Shipbuilding Corporation	Philadelphia
Stradling, George F.	Recruiting for Aviation Section, S.O.R.C.	Philadelphia
Swenson Magnus	Federal Food Administrator for Wisconsin; Chairman, State Council for Defense	Madison, Wis.
Talbot, Henry P.	Member of Advisory Board, Bureau of Mines (Gas Defense)	Cambridge, Mass.
Thomson, Elihu	National Research Council in coöperation with Council of National Defense	Swampscott, Mass.

Please send additional information and corrections to the Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, May 1, 1918.)

HALL OF THE FRANKLIN INSTITUTE.
PHILADELPHIA, May 1, 1918.

DR. H. JERMAIN CREIGHTON *in the Chair.*

The following reports were presented for first reading:

No. 2707.—Spraco Pneumatic Painting Equipment. Advisory.

No. 2714.—H. C. Snook's Improved X-Ray System.

GEORGE A. HOADLEY,
Acting Secretary.

ANNUAL REPORT OF THE DIRECTOR OF THE SCHOOL.

1917–1918.

COURSES OF INSTRUCTION.

THE ninety-fourth year of The Franklin Institute School of Mechanic Arts closed April 19, 1918. During the year instruction was given in Mechanical Drawing, Architectural Drawing and Design, Freehand Drawing, Shop Arithmetic and Algebra, Plane Geometry and Trigonometry, Applied Mechanics and Strength of Materials, and Naval Architecture.

REGISTRATION.

The total registration for the year was four hundred and eighteen, an increase of 12 per cent. over that of the previous year.

ATTENDANCE AND PROGRESS.

During the first term fifty-four students had a perfect attendance record, and forty-five had a perfect attendance record during the second term. In the regular school work thirty-seven students made an average of 90 per cent. or over during the first term and fifty-six an average of 90 per cent. or over during the second term.

Considering the urgent demand for increased production of war materials and its effect upon the leisure time of the students, the high averages in class work and attendance records indicate that the School of Mechanic Arts has completed a most successful year.

SCHOLARSHIPS.

Twenty-one scholarships were available for students of the School: eleven of these were Bartol Scholarships in Drawing, derived from the B. H. Bartol Fund; ten scholarships were derived from the Isaac B. Thorn Fund, and were awarded to students in Mathematics.

PRIZES.

Valuable prizes were offered by the following gentlemen for meritorious work in the various departments:

Mr. Samuel M. Vauclain, Vice-President, The Baldwin Locomotive Works.

Mr. J. B. McCall, President, Philadelphia Electric Company.

Mr. Wilfred Lewis, President, Tabor Manufacturing Company.

Mr. J. T. Wickersham, Secretary and Treasurer, The New York Shipbuilding Corporation.

Mr. Robert W. Lesley, Past-President, Portand Cement Association, and Member of the Board of Managers of The Franklin Institute.

The Alumni Association continued its special prizes to the graduates having the best records and to graduates having a perfect attendance for the year.

HONORS.

Certificates for the satisfactory completion of a course in one of the departments of Drawing, Mathematics, or Naval Architecture were this year awarded to fifty-two students. Appended are the names of these graduates, also the names of those students to whom were awarded the scholarships and prizes indicated above.

The success of the year that has just closed is due not only to the earnestness of the students and to their continued application to the lessons assigned, but also to the close personal attention and sympathetic interest of the instructors.

Respectfully submitted,

SIMEON VAN T. JESTER,
Director.

April 19, 1918.

LIST OF GRADUATES.

DEPARTMENT OF MECHANICAL DRAWING.

Benjamin Gordon
Charles M. Heron
Edward D. Hoban
John A. Hysore
William Henry Joseph, Jr.
Earl Leroy Lynch
Russell Morehouse
Charles F. Walker
Harry W. Walker
Milton Albert Wike
Joseph H. Wiseman

DEPARTMENT OF AGRICULTURAL DRAWING.

William Nelson Corner
John Dikaski
Lewis Oscar Egbert
David Goldstein
George W. Hardman
B. J. Krakow
James Lambert
Herbert A. Lemke
Jesse J. Moyer
Richard T. Young

DEPARTMENT OF MATHEMATICS.

Joseph P. Battle
Robert C. Black
E. L. Bromall
Charles Buckler
M. E. Chance
Harry J. Daubenschmidt
Florian R. Deppe, Jr.
Joseph Friedman
Thomas Charles Gatley
George Alvin Gieseke
Russell H. Harden
Andrew Hetherington
Robert B. Hetherington
John H. Hughes
William Kuenstle
Cyril Leech
Fred A. Niethamer, Jr.
Earl N. Rich
William F. Sanders
Albert T. Schleicher
Francis J. Sommer
Charles W. Stanley
Robert G. Staples, Jr.
John A. Stewart
Anthony Voll
Charles F. Wagner
Elmer Zeisloft

DEPARTMENT OF NAVAL ARCHITECTURE.

A. E. Copeland
Theodore G. Grier
Jacob Klonin
John L. Starr

BARTOL SCHOLARSHIPS.

DEPARTMENT OF DRAWING.

Samuel H. Collins
Ray Douglas
Francis A. Harden
Dugmore Jones
George Nairn
Franklin Oergel
John Pollano
Harry H. Riley
Harry Scott
Earl R. Watt
J. Wesley Whitehead

ISAAC B. THORN SCHOLARSHIPS.

DEPARTMENT OF MATHEMATICS.

Howard Cornwall
Fred Howarth
William Kuenstle
John McClelland
Kempton McNutt
Earl N. Rich
Herman Schaaf
Wilson D. Scott
Stanley K. Weber
Benjamin A. Wilson

PRIZES.

Earl L. Lynch—S. M. Vauclain Prize—Mechanical Drawing.
Richard T. Young—Robert W. Lesley Prize—Architectural Drawing.
J. A. Keohane—Wilfred Lewis Prize—Mechanics.
Thomas C. Gatley—J. B. McCall Prize—Mathematics.
Theodore G. Grier—New York Shipbuilding Company Prize—Naval Architecture.

ALUMNI PRIZES.

Thomas C. Gatley
William H. Joseph, Jr.
Richard T. Young
J. A. Keohane
Theodore G. Grier

FREE MEMBERSHIP FOR ONE YEAR IN THE ASSOCIATION AWARDED TO GRADUATES.

Robert C. Black
M. E. Chance
Harry J. Daubenschmidt
Lewis Oscar Egbert
Thomas Charles Gatley
Theodore G. Grier
George W. Hardman
Charles M. Heron
William Henry Joseph, Jr.
Jacob Klonin
William Kuenstle
Earl Leroy Lynch
Russell Morehouse
Jesse J. Moyer
Albert T. Schleicher
Charles W. Stanley
John L. Starr
Anthony Voll
Charles F. Walker

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, May 8, 1918.)

RESIDENT.

MR. WALTER C. HOLMES, Chief Chemist, Superior Thread and Yarn Company, Howard and Norris Streets, Philadelphia, Pa.

CHANGES OF ADDRESS.

MR. ARTHUR N. BLUM, Delmar-Morris Apartments, Germantown, Philadelphia, Pa.

MR. WILLIAM H. CRAGO, 123 Sylvan Avenue, Leonia, N. J.

DR. ERNST FAHRIG, 117 North Massachusetts Avenue, Atlantic City, N. J.

MR. WILLIAM J. FITZMAURICE, JR., 747 Marlyn Road, Philadelphia, Pa.

MR. P. M. KUEHN, Linthicum Heights, Lansdowne, R. F. D., Md.

MR. PEDER LOBBEN, Room No. 2, Keysersgade 1, Christiana, Norway.

DR. EDWARD E. MARBAKER, 622 Marlyn Road, Philadelphia, Pa.

MR. ROBERT RIDGWAY, care of Public Service Commission, 49 Lafayette Street, New York City, N. Y.

MR. C. S. VADNER, Box 594, Reno, Nev.

MR. H. H. VAUGHAN, 20 MacGregor Street, Montreal, Quebec, Canada.

NECROLOGY.

Frank Shuman was born in Brooklyn, N. Y., in 1861, and died at his home in Philadelphia on April 28, 1918.

He was educated in the common schools of his native city, and later graduated from Lafayette College.

Mr. Shuman was best known for his inventions relating to the application of the sun's heat as a motive power. His solar engine has had its widest application in Egypt because of the great amount of sunshine in that country throughout the year.

He devised a machine for mercerizing cotton and another for degreasing wool.

Mr. Shuman was the originator of wire glass, and for this invention the city of Philadelphia awarded him the John Scott Legacy Medal in 1894 on the recommendation of the Institute. Ten years later he received further recognition from the city of Philadelphia for his concrete pile for foundations.

Mr. Shuman became a member of the Institute in 1893.

LIBRARY NOTES.

PURCHASES.

American Ceramic Society.—Transactions, vol. 19. 1917.

American Society of Heating and Ventilating Engineers.—Transactions, vol. 23. 1917.

Book Review Digest.—13th Annual Cumulation. 1917.

FAHRENWALD, A. W.—Testing for the Flotation Process. 1917.

American Institute of Architects.—Structural Service Book, No. 1. 1918.

KOZMIN, P. A.—Flour Milling; a Theoretical and Practical Handbook of Flour Manufacture. 1917.

MARTIN, GEOFFREY, and Others.—Industrial Gases, Including the Liquefaction of Gases. 1916.

MURRAY, J. A. H.—New English Dictionary on Historical Principles, vols. 3–9. 1901–1914.

Poor's Manual of Industrials.—Annual, No 9. 1918.

PRIDEAUX, S. T.—Aquatint Engraving; a Chapter in the History of Book Illustration. 1909.

RUNNING, T. R.—Empirical Formulas. 1917.

TASHIRO, SHIRO.—Chemical Sign of Life. 1917.

United States Catalogue Supplement.—Cumulative Index, vol. 20. 1917.

VIALL, ETHAN.—Broaches and Broaching. 1918.

WAITE, A. E.—Lives of the Alchemystical Philosophers. 1888.

World Almanac and Encyclopedia. 1918.

BOOK NOTICES.

THE SCIENCE AND PRACTICE OF PHOTOGRAPHY: AN ELEMENTARY TEXT-BOOK ON THE SCIENTIFIC THEORY AND A LABORATORY MANUAL. By John R. Roebuck, Ph.D. New York, D. Appleton and Company, 1918, 287 pages, contents and index, illustrations, 8vo. Price, $2.00.

There is a great deal of useful information for photographers, both professional and amateur, in this book. As the author is a teacher of physics, it has been given more the character of a student's text-book than a reference work, but this does not interfere with its usefulness. The course, as outlined, requires an elementary knowledge of mathematics, physics, and chemistry. The author is, doubtless, right in criticising unfavorably the reliance of many photographers upon empirical methods, and neglecting the theory of the processes. Those who are to-day acquainted with the aims of photographic exhibitions know well how little the technical side of the science attracts. In these exhibitions, and in the slide-interchanges of the American photographic societies, a picture that shows some phase of pure technic, such as development after fixing, pinhole work, reversal of image, is passed over by the judges, and the first prize is apt to go to a picture that is about as vivid when upside down as in the proper position.

The book opens with a historical introduction, in which the work of Niepce, Daguerre, and Talbot leads off; then follow paragraphs on collodion, gelatin, and the dry-plate. An interesting account is given of the methods of manufacture of the common dry-plate emulsions. The properties of the gelatin plate are treated extensively, including the theory of the latent image, after which follows a consideration of the ordinary defects of negatives, with which beginners, and even some old hands, are only too familiar. The making of positives is then taken up, after which the theory of lenses is discussed. Color photography and the general principles of artistic picture-making are included in the next chapters. After consideration of development and speed data, sixty pages are devoted to the "Laboratory Manual," which is a series of valuable experiments in photographic procedure.

The book is well printed with large, clear type, and freely illustrated, mostly with line drawings. The photogravures are generally poor. The frontispiece, which is intended to illustrate autochrome work, is, in the copy in the reviewer's hands, so badly out of register as to be worthless. A reproduction of a pinhole picture is given, but here again the mechanical execution of the plate is poor and the view chosen is not at all adapted to show the capacities of such methods for artistic work. Architecture is often very attractively rendered by the pinhole; indeed, it is generally conceded that the perspective is better than that yielded by most lenses. Another interesting feature of pinhole work is that views may be taken where there is rapidly-moving traffic, without this interfering with the picture.

HENRY LEFFMANN.

LABORATORY GUIDE TO INDUSTRIAL CHEMISTRY. By Allen Rogers. New York, D. Van Nostrand Company, 1917. Second edition, entirely rewritten and enlarged. 204 pages, contents and index, illustrations. 8vo. Price, $2.00 net.

The author, in the preface, states that this book is a plea for a more extended teaching of industrial chemistry in technical schools, and it is well calculated to serve this purpose, for it contains a large amount of information of the most practical character. It presumes that the student possesses a knowledge of the general principles of chemistry, which is, of course, a proper view, for no student should take up such work unless quite familiar with the modern theories of chemical action, and especially with stoichiometry.

The topics covered by the book are: General Process, Inorganic Preparations, Organic Preparations, Dyeing of Textiles, Pigments and Lakes, Driers, Varnishes, Paints and Stains, Soap and Allied Products, Leather, Wood-fibre, Pulp and Paper. Ten pages of Useful Data, including tables and rules for certain calculations, close the book. The work is, of course, useful only to the student, not being intended to take the place of the large reference works in this field. It is well printed.

HENRY LEFFMANN.

REPORT ON THE PROGRESS OF APPLIED CHEMISTRY, issued by the Society of Chemical Industry, vol. 1, 1916. London, Harrison and Sons, 1917. 315 pages and index. 8vo. Price, 5s. 6d.

The *Journal of the Society of Chemical Industry* has been for so many years favorably known to chemists interested in the practical phases of the science that the present volume will need no special recommendation. It is a new venture, and is not a collection of abstracts or a reprint of articles from the *Journal*, but independent reports of specialists giving the more important developments, up to the end of 1916, in many departments of applied chemistry. Agricultural and food chemistry, and analytic methods as such, are not included, as these are treated in the reports of the Chemical Society. For obvious reasons, explosives are not considered in the present volume. The book is well printed, contains a large amount of highly valuable data, and its appearance, as the initiator of the series, will be good news to chemists.

HENRY LEFFMANN.

PRINCIPLES OF AGRICULTURAL CHEMISTRY. By G. S. Fraps, Ph.D. Easton, Pa., Chemical Publishing Company, 1917. Second edition, 490 pages, contents and index, illustrations. 8vo. Price, $4.50.

Few phases of chemistry are to-day more important than the agricultural. The citizen sees staring at him from almost every point available the slogan "Food will win the war," and every one knows that the source of all food is the earth. Extensive as have been the studies of the chemistry of growing crops and of animal development, much still remains to be done in this field. In the main, the farmer is not fully alert to the more recent science, and many parts of the earth still fail to yield the return that theory indicates and that the labor bestowed on them should procure.

The work before us is a comprehensive statement of the principal phases of the chemistry of plant growth, nature of soils, composition and value of fertilizers, processes of animal digestion, and practical directions as to the methods of feeding food animals and of conducting studies in both plant

and animal nutrition. Some information is given as to procedures in analysis; but the book has not been written as an analytic manual nor as a treatise on chemistry. There are nearly one hundred illustrations, many of which are commendable, some not so, some indeed essentially useless. The pictures of an Alpine glacier (p. 56), a limestone cavern (p. 58), and of the sections of porphyry and granite (p. 64) are not ornaments to the book. Similarly, the cheap cut of polarimeter (erroneously called polariscope) was not worth printing.

The reviewer regrets that the author has been careless as to chemical nomenclature. The term "proteids" is now generally abandoned for the term "protein," and it is a mistake to say that feldspars "contain potash, soda, and lime." They yield these substances under certain treatment, but do not contain them. It is true that many farmers and dealers use such terms, but this book is intended for the instruction of scientists, and should observe the scientific forms.

The book is well printed and contains a large amount of valuable information.

HENRY LEFFMANN.

LECITHIN AND ALLIED SUBSTANCES, THE LIPINS. By Hugh Maclean, M.D., D.Sc. London, Longmans, Green & Co., 1918, 206 pages, 8vo. Price, $2.25.

This treatise is one of the series of monographs on biochemistry edited by R. H. A. Plimmer and F. G. Hopkins. Maclean uses the term lipin as a class name to include the phosphatides (substances containing fatty acids, nitrogen, and phosphorus) and the cerebrosides (substances containing fatty acids, nitrogen, and a carbohydrate group, but no phosphorus), and offers the following definition: "Lipins are substances of a fat-like nature yielding on hydrolysis fatty acids or derivatives of fatty acids and containing in their molecule either nitrogen, or nitrogen and phosphorus." The phosphatides recognized as chemical entities are: lecithin and kephalin (monaminomonophosphatides), sphingomyelin (a diaminomonophosphatide), and cuorin (a monaminodiphosphatide); the cerebrosides recognized as chemical entities are phrenosin and kerasin. One chapter is devoted to the chemistry of the phosphatides, another to their occurrence, and the methods used for their extraction, isolation, and purification. The cerebrosides and protagon are discussed with the same detail as the phosphatides. Protagon is defined as "certain mixtures of cerebrosides and sphingomyelin obtained from organs by extraction with hot alcohol and other solvents. For this purpose it is perhaps worth while retaining a name which has ceased to have any meaning in the chemical sense, but is of some importance from the practical point of view." Alleged lipins and plant lipins receive attention in separate chapters.

The concluding chapter describes the function of lipins, their relation to metabolism, growth, narcosis, and certain oxidative processes (oxydases and respiration of plants), and also their action on digestive enzymes. The author was called to France before the completion of this chapter, and it became necessary to omit a section on the phenomena of hæmolysis and immunity, or else to postpone publication indefinitely. The conclusion is

reached that, at present, the special part played by the lipins in the activity of the organism is entirely unknown to us.

A bibliography of 22 pages is appended.

JOSEPH S. HEPBURN.

ALLEN'S COMMERCIAL ORGANIC ANALYSIS. Edited by W. A. Davis. Fourth edition, volume IX. Philadelphia, P. Blakiston's Son & Co., 1917, 836 pages, 8vo. Price, $5.

This volume forms a supplement to the preceding eight volumes. Its purpose is given in the preface: "Since the revision of this work was first undertaken in 1907, a considerable amount of literature has appeared and many new methods of analysis have been devised. It, therefore, became desirable to issue a supplementary volume bringing the text, especially that of the earlier volumes, up to date. The new articles have, as far as possible, been written by the contributors to the earlier volumes, but, in a few cases, pressure of other work caused by the outbreak of war has made it necessary to entrust the revision to other hands." The new contributors are: A. J. Ewins, K. G. Falk, P. B. Hawk, R. Lessing, R. H. McKee, J. R. Powell, P. J. Sageman, J. P Street, Arthur W. Thomas, and J. B. Tuttle.

The volume is divided into sections on: Alcohols; malt and brewing materials; wines and spirits; yeast; neutral alcoholic derivatives; sugars; starch and its isomerides; paper and paper making materials; aliphatic acids; fixed oils, fats and waxes, their special characters and modes for their examination; butter fat; lard; linseed oil; soaps; glycerol; cholesterol; wool, grease and cloth oils; hydrocarbons, bitumens; naphthalene and its derivatives; phenols; aromatic acids; resins; india-rubber, rubber substitutes and gutta-percha; essential oils, and their special characteristics; tannins; leather analysis; coloring matters, their analysis, those of natural origin, and those in foods; inks, and printing inks; amines and ammonium bases; aniline and the naphthalamines and their allies; vegetable alkaloids (separate chapters on volatile alkaloids; those of aconite, opium, strychnos, and cinchona; atropine and its allies; cocaine; berberine and its associates; caffeine, tea and coffee; and other alkaloids); glucosides; non-glucosidal bitter principles; animal bases and acids; lactic acid; cyanogen derivatives; enzymes; proteins, with chapters on those of vegetable origin and of milk; milk products; albuminoids; meat and meat products; and fibroids. Additional supplementary matter is given in an appendix. Besides an index to Volume IX, a general index is included, covering the entire set of nine volumes, authors and subjects being listed separately.

JOSEPH S. HEPBURN.

THE PHYSICAL CHEMISTRY OF THE PROTEINS. By T. Brailsford Robertson, Ph.D., D.Sc. New York, Longmans, Green & Co., 1918, 483 pages, 8vo. Price, $5.00 net.

In the preface Robertson states: "I have endeavored to interpret the physico-chemical behavior of the proteins in the light of the laws of Boyle and Gay-Lussac, as they have been applied to solutions by van 't Hoff, and of the Guldberg and Waage mass-law, which, as Larmor has shown, is a direct consequence of Avogadro's rule and Boule's Law. I have also assumed

the validity, in protein systems, of the first and second laws of heat; albeit the applicability of the second law of heat to protein systems has, in some quarters, been questioned. In considering the *electrochemical* behavior of the proteins I have assumed the applicability of Arrhenius' hypothesis of electrolytic dissociation, of Kohlrausch's law of the independent motion of ions, of the Nernst theory of concentration-cells, and further, although this has of recent years been very strongly questioned, the applicability of the Guldberg and Waage mass-law to reactions between ions. I believe that the utility of these hypotheses justifies us in applying them until still more useful hypotheses shall have been elaborated to amplify or replace them."

The treatise is divided into four parts. Part I, Chemical Statics in Protein Systems, includes chapters on the chemical constitution of the proteins, their preparation in the pure state, their quantitative estimation, and their compounds with other compounds—inorganic, organic, and biological—acid, basic, and neutral. Part II, The Electrochemistry of the Proteins, is devoted to chapters on the formation and dissociation of protein salts, the combining capacity of the proteins, the electrical conductivity of their solutions, and the electrochemistry of coagulation. Part III, The Physical Properties of Protein Systems, opens with a discussion of the phenomena accompanying the changes in the state of aggregation of proteins; the optical and other physical properties of protein solutions are then described. In Part IV, Chemical Dynamics in Protein Systems, attention is paid to the hydrolysis of the polypeptides and the proteins, and to the enzymatic synthesis of proteins. The technic of electrochemical measurements in protein systems is discussed in an appendix. Subjects and authors are indexed separately. A bibliography is given at the end of each chapter, covering the literature to the middle of the year 1917.

JOSEPH S. HEPBURN.

PUBLICATIONS RECEIVED.

The Chemical Analysis of Iron: A complete account of all the best-known methods for the analysis of iron, steel, pig-iron, alloy metals, iron ore, limestone, slag, clay, sand, coal, and coke, by Andrew Alexander Blair. Eighth edition. 318 pages, illustrations, 8vo. Philadelphia, J. B. Lippincott Company, 1918. Price, $5.

James Woodhouse, a Pioneer in Chemistry, 1770–1809, by Edgar F. Smith, Provost of the University of Pennsylvania. 299 pages, plates, portrait, 12mo. Philadelphia, John C. Winston Company, 1918.

Cours de Mécanique professeé a l'école polytechnique par Léon Lecornu, tome iii. 668 pages, illustrations, 8vo. Paris, Gauthier-Villars, 1918. Price, 25 francs.

Lecithin and Allied Substances: The Lipins, by Hugh Maclean. 206 pages, 8vo. New York, Longmans, Green and Company, 1918.

North Carolina Geological and Economic Survey: Economic Paper No. 46, The Vegetation of Shackelford Bank, by L. F. Lewis. 40 pages, plates, 8vo. Economic Paper No. 47, Proceedings of the Ninth Annual Drainage Convention of the North Carolina Drainage Association, held at Greensboro,

North Carolina, November 22 and 23, 1916, compiled by Joseph Hyde Pratt, State Geologist, and Miss H. M. Berry, Secretary. 110 pages, illustrations, 8vo. Raleigh, State Printers, 1917.

U. S. Bureau of Mines: Bulletin 103, Mining and Concentration of Carnotite Ores, by Karl L. Kithil and John A. Davis. 89 pages, illustrations, plates, 8vo. Bulletin 137, The Use of Permissible Explosives in the Coal Mines of Illinois, by James R. Fleming and John W. Koster. 110 pages, plates, 8vo. Bulletin 155, Oil-storage Tanks and Reservoirs, with a Brief Discussion of Losses of Oil in Storage and Methods of Prevention, by C. P. Bowie. 76 pages, illustrations, plates, 8vo. Monthly Statement of Coal-mine Fatalities in the United States, January, 1918. List of Permissible Explosives, Lamps, and Motors Tested Prior to February 28, 1918, compiled by Albert H. Fay. 23 pages, 8vo. Coal-mine Fatalities in the United States, 1917, compiled by Albert H. Fay. List of Permissible Explosives, Lamps, and Motors Tested Prior to January 31, 1918. 37 pages, 8vo. Washington, Government Printing Office, 1917–1918.

Non-inflammable Plastic Material. ANON. (*The Chemical Trade Journal and Chemical Engineer*, vol. lxi, No. 1589, p. 365, November 3, 1917.)—A recent French patent describes a new plastic material which is non-inflammable and odorless. The material is obtained by transforming gelatines, glues, and such substances of animal origin by suitable chemical reagents, giving them plastic and malleable properties which allow them to be used industrially in a manner similar to natural products.

The gelatines or glues are first melted in a water-bath at a temperature of 90° C. A decoction of hop flowers is then prepared and mixed with dilute oxalic acid or any dibasic acid of that series, and the solution is added to the melted gelatines or glues in varying proportions, according to the quality of the materials employed. The addition of this solution has the effect of rendering the gelatine more supple and of causing the impurities they contain to deposit at the bottom of the vessel. When the gelatines are liquefied they are poured out in the form of sheets or sticks of the desired thickness and left to dry in the cold air. The coloring of the material is then proceeded with, natural or artificial dyes being employed. The sheets, when colored, are plunged into a bath of approximately the following composition: 25 to 35 per cent. formaldehyde, 25 to 35 per cent. water, 25 to 35 per cent. alcohol, and the rest composed of a mixture of oxalic acid, tannin, and glycerine.

The oxalic acid may be replaced by any other acid of that series. The plates should be left in this solution until the liquid has penetrated into the entire plastic mass. In the case of rich gelatines, the proportion of alcohol must be increased. The sheets, when taken out of the bath, are dried, preferably in hot air. The substance, when suitably worked, may serve for the manufacture of combs, buttons, brushes, etc., as an imitation of tortoise shell, horn, amber, or ivory, and is unlike other cellulose products used in industry, in being absolutely non-inflammable and odorless.

CURRENT TOPICS.

Colored Silk Effects on Cloth. ANON. (*The Dyer and Calico Printer*, vol. 88, No. 454, p. 227, December 15, 1917.)—Silk effects have been produced in printing by means of finely powdered metal suspended in a binding medium. With all its advantages, this method has two drawbacks, the first being that among the metallic powders available for such purposes there is not a single one that is actually white; that chiefly employed for the purpose, aluminum powder, is grayish blue. The consequence of this is that in using metallic powder processes it is not possible to produce a pure white on light substances. It is only on dark substances by contrast that the effects printed with metallic powders appear white. The second drawback is the impossibility of printing any particularly desired tints with metallic powder, the printing being restricted to such shades of color as are found in the aniline colors. The metallic powders colored with coal-tar colors, moreover, owing to the colors lying only on the surface, have the disadvantage that, when rubbed, the color is removed and the metal beneath exposed. Coloring the binding medium is not practicable, as this is not easily colored, and the metallic powders suspended in the medium, which are colored with great difficulty, alter the color, and in certain circumstances entirely nullify the effect.

To overcome these faults an Austrian chemist has invented a process by which it is possible to obtain silk-like, glossy effects in pure white or in any color. The method is based on the principle of mutual action of cellulose and cellulose derivatives and finely powdered mica. The employment of mica adhesively attached to woven materials is well known, but the gist of the new process is the highly effective and in every respect genuine result produced by the combined action of mica and cellulose derivatives. If an impression is made on a ground with a solution of cellulose nitrocellulose, viscose, or acetate of cellulose, in no instance is a silk effect produced either with or without subsequent calendering. The ground shows through the transparent impression and the desired effect is not produced.

By the addition of a substance producing non-transparency, for example, a powdered white coloring body, no better result is obtained than by using the white coloring body in combination with another binding medium. On the other hand, it can easily be shown that finely powdered mica in ordinary media does not produce silk-like, glossy effects. Neither gelatin nor albumin, the carbohydrates still employed as media, solutions of resin, or any kind of varnish produce satisfactory glossy, silk-like effects, as these binding media more or less completely obscure the lustre of the mica. Only by the employ-

ment of mica in combination with cellulose, nitrocellulose, viscose, and other derivatives of cellulose are silk-like, glossy effects produced. It is expressly pointed out that cellulose and its derivatives do not act exclusively as binding or fixing media for the finely powdered mica; the mica could be equally well fixed, or in certain instances even better, with other fixing media—for example, gelatin, albumin, varnish, and solutions of resin. What is actually under consideration is the combined action of the mica with the cellulose derivatives which are known to possess a silk-like lustre. As the solutions of cellulose derivatives can easily be colored without injuriously affecting their lustre and that of the mica when the drying is effected, and without having their tints undesirably modified by the mica, it is possible to produce colored, silk-like, lustrous printing effects, the tints of which are entirely under the control of the colorist. The process consists in dissolving the cellulose or its derivatives and mixing it, colored or uncolored, with finely powdered mica, and printing upon the ground with the resulting paste. The following proportions give good results: 100 parts by weight of a 15 per cent. solution of nitrocellulose (nitrate of cellulose), pyroxyline, collodion cotton, etc., in a suitable solvent, as amylacetate, butylacetate, etc., to which a small quantity of a softening medium, as castor oil or glycerine, may be added, are thoroughly mixed with 8 to 10 parts in weight of finely powdered mica.

Photographic Surveying in Canada. ANON. (*British Journal of Photography*, vol. 65, No. 3009, p. 5, January 4, 1918, from *Geographical Review*.)—Photographic surveying may be used in any class of country where the topographical features are sufficiently marked to appear clearly in the photographs. The method, however, is best adapted to rugged country, such as the high mountain ranges of British Columbia and Western Alberta. Here the season during which climbing may be accomplished with safety is short, and climatic conditions are often unfavorable. High winds, storms, clouds, and extreme cold are the rule, so that work must often be done hurriedly and under great difficulty.

On Canadian photographic surveys the essential instruments are a camera and a small transit. These instruments are of the simplest possible form. In this respect they show a marked contrast to the complicated designs of most European instruments. The camera consists of an oblong metal box, open at one end and fitted into a strong outer wooden case. The metal box carries the lens and two sets of cross-levels, and views may be made with the long side of the plate either horizontal or vertical. The instrument stands on a three-screw base identical with that of the transit, so that the same tripod may be used for both. The size of the plates is 6¾ x 6½ inches. Owing to the excessive contrasts of Alpine scenery, orthochromatic plates and a color screen are essential.

When in the field it is important to select those points which give the best views of the surrounding country. It is customary to take

enough views from each peak to cover the complete circuit of the horizon. It seldom happens, however, that all the views can be taken from a single point. Usually a number of camera stations are required on different parts of the peak, and located by reading angles on them from the central point and measuring the distance with a light tape. Angles of elevation or depression should also be read at these points to check the horizon line.

For plotting purposes bromide enlargements, approximately 10 x 14 inches, are made from the negatives. This must be very accurately done to obtain satisfactory results. Views from different stations showing the same country are selected, and sufficient points are identified on each of two corresponding views, taken from the different stations, to show the topography of the country. These points are then plotted on the plan and their elevations calculated from the photographs.

Cleaning Mill Spots from Silks. ANON. (*American Silk Journal,* through *The Dyer and Calico Printer,* vol. 88, No. 454, p. 234, December 15, 1917.)—Almost from time immemorial there has been more or less trouble experienced in cleaning and spotting silks soiled in the mill in the process of manufacturing. Because of the peculiar structure of silk, the inorganic matter which is frequently put into it, and the fact that the dyes are not always fast, it is difficult to use spotting agents without leaving rings or other discolorations in attempting to remove oil or grease spots or stains, however caused. Spotting solutions used for cleaning purposes should not contain alcohol or ammonia. Some of the basic dyes used for silks are very sensitive to alcohol, and ammonia discolors white and light-tinted silks. Notwithstanding that even a harmless bit of white soft silk waste may be used for cleaning, the silk fabric should never be rubbed on its face. All spots should be removed from the back of the cloth with the face of the material on a clean white cotton or woollen cloth or white blotting-paper, which will attract the spot from the silk by absorbing it.

Every precaution should be taken against leaving rings on the silk when using spotting agents. For instance, when benzine is used for cleaning, it should be strained through salt to remove the moisture. A funnel may be used for this purpose, over which a piece of clean white cotton cloth is laid to hold the salt. Before using, the benzine should be filtered through the salt. Chloroform readily removes oil and grease stains from white silks. Used on dyed silks, it is apt to affect the color. Carbon tetrachloride is recommended for colored silks. If these reagents are used in a warm condition, they evaporate quicker from the silk. Paint stains may be removed from silks by aniline oil, followed by ether. Ink spots are sometimes affected by a dilute solution of oxalic acid after alcohol has been tried. Acetic acid used for removing ink stains will be found less harmful to colors than oxalic acid. Slight steaming will remove water spots from silk.

Fixation of Nitrogen. H. LEFFMANN. (*Transactions of the Wagner Free Institute of Science,* vol. 8, July, 1917.)—The amount of nitrogen in the part of the universe with which we are acquainted is immense, much of it being in the free state in the atmosphere. In view of the possible near-exhaustion of the sodium nitrate deposits of South America, and the slowness with which nitrates can be produced by ordinary methods of decomposition, agricultural chemists have for some years been turning their attention to the discovery of methods of causing the nitrogen of the atmosphere to unite with other elements so as to produce compounds that may be employed for enriching the soil. These processes are also invaluable in another department of human industry; namely, the manufacture of explosives.

A peculiar and interesting utilization of nitrogen takes place in soil, in connection with the growth of some plants, especially those belonging to the large and widely distributed natural order, *Leguminosæ*. To this order belong several important food plants, such as peas and beans; important grazing plants, such as clover and alfalfa, and many trees, such as the honey-locust, the Kentucky coffee-tree, and the acacias. The roots of many of these plants bear nodules that are collections of bacteria, which use the roots as a physical support and carry on processes by which nitrogen is fixed and rendered available for the use of the host plant. It has long been known that the fertility of land can be materially increased by planting clover and plowing it in after it has reached good growth. These processes of nitrogen-fixation are slow, and the nitrogen compounds must be utilized in the place in which they are produced for the growth of plants, so that one very important application of fixed nitrogen, that for the manufacture of explosives, is not met by this method.

Nitrogen was formerly considered one of the most indifferent of elements, but research has brought to light a few elements—gases at ordinary temperatures and existing in small amount in the air—which are apparently without chemical affinity. Free nitrogen combines directly, even under the influence of high temperature, with but few elements, of which one is magnesium. Under the influence of the electric spark, direct combination of the nitrogen and oxygen of the atmosphere can be effected. This was discovered in the eighteenth century, in the course of researches by Henry Cavendish and Joseph Priestly. Whether the combination is due to the increase of the affinity of the nitrogen or the oxygen, or both, is not definitely known. It is known that pure oxygen can be converted by electric discharges, especially the so-called "silent discharge," into the much more active form, termed "ozone," without an alteration in fundamental composition. Cavendish used the spark of a static machine, and some modern apparatus for producing ozone use discharges of high voltage currents, either through a special dielectric or directly through dry air.

The direct oxidation has been carried out in several ways, but present usage is limited to the flaming arc. One of the best known and apparently most successful forms of apparatus is the Birkland-Eyde furnace, which depends on developing an arc by an alternating current of high voltage in a constant magnetic field, the arc spreading out under the influence of the magnetic field in the form of a fan at each electrode. As current can easily be obtained at low cost by water power, the operation of such plants has been especially developed in mountainous countries, such as Switzerland and Scandinavia. Abundant opportunities for such development exist in the United States.

Calcium carbide has been manufactured for many years in large amount for the production of acetylene; when this compound is heated to about 1000° C. in a current of nitrogen, direct combination takes place, with the formation of calcium cyanamide. Calcium cyanamide may be used directly as a fertilizer, and, as it contains 4 per cent. more of available nitrogen than sodium nitrate, it is being prepared on a very large scale. This product is marketed in a finely powdered form, often under the name "nitrolim." The process is carried out either by heating the carbide by means of an electric arc within the mass, or in retorts by direct outside firing. The cyanamide processes differ from the nitrogen-oxidation processes by the fact that the former require practically pure nitrogen, while in the oxidation processes the raw material is air, which is obtainable in unlimited amount. The fertilizing action of calcium cyanamide is dependent essentially upon its power of yielding ammonium compounds under the influence of moisture, with probably the coincident action of soil bacteria.

Synthetic ammonia may be produced by the direct action of nitrogen and hydrogen in a high state of purity. Their union is accomplished by the joint action of heat pressure and a catalyst. The practical investigation of the synthetic production of ammonia is due to Haber and Le Rossignol. They found that by employing a pressure of about 200 atmospheres, a temperature between 500° and 700° C., and passing the gases over a catalyst, from 3 to 12 per cent. of ammonia could be obtained. The technical difficulties of manipulation involved in this process appear to be serious, and the record of its achievement is not favorable, at least in its present state of development.

Recently another process of nitrogen-fixation devised by Prof. John F. Bucher has been announced. Briefly, this consists in passing air over heated coal or coke previously mixed with an alkali, and with finely divided iron, which acts as a catalyst. An alkali cyanide results. (See this JOURNAL, May, 1917, p. 665.)

Photographic Resolving Power. K. HUSE. (*Journal of the Optical Society of America*, vol. 1, No. 4, p. 119, July, 1917.)—Photographic resolving power is generally defined in terms of the distance by which two minute images lying adjacent to one another

are just separated on the developed plate. In the judgment of the separation it is assumed that the image is so viewed as to be well within the resolving power of the eye and not magnified to an extent that will make the individual silver grains more apparent than their groupings. This is a logical definition, strictly in accord with that of the resolving power of optical instruments, but it should be pointed out that the measurement of photographic resolving power is not an angular measurement, but a linear one.

The method employed of determining this resolving power is that devised by Mees, and consists in accurately photographing a test-object, a fan-shaped converging grating, divided into alternate light and dark sectors, each including an angle about 1.5 degrees. The minute image thus obtained, only one millimetre long, is examined under a micrometer microscope to ascertain the distance from its apex the image is resolved. The spacings of the grating and the scale of reduction being known, a numerical expression for the resolving power is found. Thus a value of fifty means that the plate or film under the conditions of the experiment is capable of resolving fifty lines to the millimetre, measured from centre to centre.

Photographic resolving power has been studied by the fan-grating test to ascertain the effect of exposure, development, developer used, and the wave-length of the incident light. It was found that resolution is, in general, extremely sensitive to time of exposure, over- and under-exposure being decidedly detrimental. It also depends upon the time of development and upon the reducing agent employed. If two plates of the same emulsion, exposed equally and under the same conditions, are developed in different developers, the values of resolving power obtained vary widely, the greatest deviation from the maximum value being of the order of forty per cent. with the developers tested. Thus resolution is not a definite property of an emulsion, but it is dependent also upon its treatment in the photographic process. With regard to the effect of the wave-length of the incident light, resolution was best for light of the short wave-lengths, with a decided minimum in the green, increasing again in the red, though not to as high a value as with blue light.

Placer Platinum in California and Oregon. ANON. (U. S. Geological Survey, *Press Bulletin*, No. 356, February, 1918.)—Platinum, osmium, iridium, palladium, ruthenium, and rhodium form a group of closely related metals, which are generally found as native metals more or less alloyed with one another. They are rarer than gold, and some of them, especially platinum, iridium, and palladium, are now more valuable and in greater demand than gold. Under normal conditions the United States requires about 165,000 ounces of the platinum metals a year. It produces only a few thousand ounces, and is meeting increasing difficulties in importing sufficient quantities. Therefore these metals should be applied only to their most essential uses.

The platinum metals are found in quantities of economic value at only a few places. The bulk of the world's production has heretofore been furnished by the placers of the Ural Mountains, in Russia, but the production from this source is decreasing. Colombia is becoming an increasingly large producer. In the United States there has been a small but steady production of platinum for many years from the gold placers of northern California and southern Oregon.

In these new emergencies we find that we have not utilized all our natural resources and that we have lacked the imagination to foresee the value of some of these resources. Henry G. Hanks, a former State mineralogist of California, as far back as 1884 made the following statement: "If the miners could be persuaded to collect the platinum minerals an industry might be established of considerable importance. There is no reason why platinum should not be manufactured in San Francisco and the American demand in part or wholly supplied by this state." It is said that the platinum metals were thrown away by the miners in the early days because there was no demand for them. The things that are thrown away by one generation, however, are picked up and saved by the next, and the work of saving these valuable metals is now in progress.

In view of the increasing difficulty of obtaining sufficient supplies of these metals a comprehensive survey of our platinum resources was begun by the United States Geological Survey, Department of the Interior, during the field season of 1917. The work in California was done in coöperation with the California State Mining Bureau. Most of the platinum that has been produced in the world has come from placer mines, and much of it has been derived from placers that were worked primarily for their content of gold, such as those in California and Oregon. In these places the platinum metals are associated with the gold. The important facts regarding their occurrence are their widespread distribution and their lack of concentration in high value at any particular locality. In most places the proportion of the platinum metals to the gold is very small. At one placer where large quantities of gravel were being handled the proportion of platinum to gold was about one-tenth of 1 per cent. by weight. In a few small operations the proportion of platinum was reported to be equal to the gold, and in still fewer it was reported to be more than the gold.

The problem of increasing the production of the platinum metals is closely involved with the production of placer gold and may be resolved into the problems of saving a larger proportion of platinum from the ground now mined and of finding new productive areas. California has been the best area in the world for developing methods of placer mining. The Golden Age of hydraulic and drift mining, however, has passed away. The method now in use, which handles the greatest quantity of gravel and saves the most gold, is dredging.

The platinum metals are generally supposed to be derived from

the serpentine that occurs in many areas in northern California and southern Oregon. Wherever platinum seems to have been traced nearly to its source this rock is found. A roughness of the platinum and in some specimens a black or brownish coating, which is apparently iron oxide, indicate proximity to its source, but it has not yet been traced directly to the serpentine, although it is probably derived from this rock. The large areas of serpentine and related rocks in northwestern California and southwestern Oregon and the gold and platinum found in many of the streams that drain them make this country favorable for prospecting not only for the platinum metals, but for chromite, manganese, and cinnabar.

The possibility of increasing the production of the platinum metals, then, depends on improvements in the methods of saving now used, on the extension of these methods to areas that are known to contain these metals but that have not yet been mined, and on the discovery of new productive ground in northwestern California and southwestern Oregon, where the prospects seem to be good. Streams that carry insufficient gold and platinum to pay for mining at the prices formerly prevailing might now yield a profit. Streams that drain areas of serpentine would seem to be particularly favorable for prospecting. At no place are the platinum metals concentrated in large quantities. Being rarer than gold, they are harder to find than gold. Iridium is in great demand, and the fact that it forms 10 to 40 per cent. of the platinum metals in nearly all the placer deposits in the United States is a special incentive to the search for more of them. The risk that must be taken to find and develop new sources of supply is great, but the pressing need would seem to justify it.

The elimination of litigation and the equitable settlement of questions regarding surface rights and underground rights in drift mining and regarding the distribution of water for irrigation, power plants, and mining might also increase the output. The present price of the platinum metals, which is higher than that of gold, does its share in encouraging production.

Strength of Weld in Wrought-iron Pipe. ANON. (*The Gas Age*, vol. 41, No. 1, p. 36, January 1, 1918.)—Welded pipe made of wrought iron or steel is always subjected to a hydrostatic test before leaving the mill. The range of pressure applied in ordinary practice is from 250 pounds up to 2000 pounds per square inch, the great majority of sizes of standard weight pipe being tested under a pressure of 750 to 1000 pounds per square inch. As the hydrostatic test is an evenly applied bursting load of short duration, it does not insure against splitting of pipe at the weld under torsional, tearing, or compression stresses which are encountered in the course of cutting, threading, bending, and installing.

The strength or dependability of the weld in iron and steel pipe

has sometimes been open to question, and as every pipe specialist knows from experience, new pipe may show a tendency to split under stresses apparently much below the hydrostatic test pressure. When the pipe is well made from a good grade of material, the percentage of such failures should become negligible, although they may not be entirely avoidable. In fact, lap-welded pipe should be especially reliable.

The subject has been quite thoroughly studied by pipe manufacturers for the purpose of improving their product. For example, in order to further minimize the percentage of weld failures, the A. M. Byers Company, of Pittsburgh, Pa., subjects all crop ends of pipe, the point where the greatest number of defects will naturally occur, to a crushing test.

A series of flattening tests on pipe, which had already been subjected to the mill tests referred to, have been carried out by Edward A. Klages, of the University of Pittsburgh. One hundred and sixty pieces of pipe of various sizes, both butt-weld and lap-weld, were tested, the pieces being placed at varying angles to the vertically applied pressure. Of the 160 pieces tested, including all sizes from 1 to 12 inches of different weights, only 12½ per cent. showed commencement of failure at the weld. In spite of the excellent welding quality of genuine wrought iron, for which this material has always been favorably known, the results of the tests were a little surprising in showing, in the main, less tendency to fracture at the weld than elsewhere, thus leading to the conclusion that the weld in genuine wrought-iron pipe is at least as strong as the body metal for a like application of stress. This was shown also by the fact that the position of the weld with respect to the applied load in flattening had no influence upon the location of the place of initial failure.

Decay in Wood in Buildings. ANON. (*Wood Preserving*, vol. 4, No. 4, p. 54, October–December, 1917.)—Much discussion during the past year occurred in the technical lumber press over the decay of wood in buildings. Several cases of bad failure were reported. Research was started by the Forest Products Laboratory at Madison, Wis., to determine the "killing points" in temperature and humidity of common fungi found in American buildings. These studies have already yielded data of considerable importance. It was found, for example, that with a temperature approximately 100° F., and a high humidity, the mycelia of certain fungi can be killed. This is contrary to a popular conception that methods of arresting growth of these fungi involve the use of hot dry air.

Field and laboratory studies indicate that much more care should be exercised in the selection of timber and in the construction of buildings to avoid conditions favorable to decay. A number of inspections of buildings which have given trouble on account of decay

have shown that any one of the following causes may result in rapid deterioration of the building: (1) the use of green lumber; (2) allowing lumber to get wet during construction; (3) allowing the lumber to absorb moisture after the building is finished, because of leaks or lack of ventilation; (4) the use of lumber containing too much sapwood; (5) the use of lumber which has already started to decay. The avoidance of these conditions will, as a rule, prevent decay. In special cases, however, decay can be prevented only by preservative treatment. For this purpose salts, such as zinc chloride and sodium fluoride are recommended.

Melting Cast Iron in Crucibles. ANON. (*Graphite*, vol. 20, No. 2, pp. 4288 and 4290, February, 1918.)—It often happens that one must have an iron casting in such a hurry that in the time consumed to have the casting made in the ordinary way the use for the casting is almost over. Every one who operates a brass foundry but has no iron foundry can make iron castings quickly and cheaply in his crucible furnace, for he has all the equipment necessary for making these hurried important little iron-casting jobs, and the casting can be made almost before the pattern has reached the iron foundry.

Gray iron of the better kind melts at 2327° F., and, while this may appear to the brass founder to be a high heat compared with that for the yellow brass or composition metal he regularly melts, the melting is easily done in a graphite crucible, and is so simple that it is surprising that the practice is not more general. Alternate layers of charcoal and gray iron, broken to pieces about the size of walnuts or larger, are packed in a graphite crucible and melted in the pit brass furnace. An iron casting of high grade will be secured in a very little longer time than it takes to make a brass casting. The bottom of an old brass crucible may be used as a cover to keep out sulphur fumes and coal and hasten the melting.

The crucible melting of cast iron may also be carried on in a gas furnace. For the production and melting of aluminum alloys gas-heated furnaces are being employed that hold crucibles of 600 pounds' capacity when melting copper and approximately 200 pounds capacity for aluminum. In many instances cast iron is being melted in crucibles of 60 to 100 pounds' capacity for the production of high-grade castings; and, although the fuel costs are considerably higher than when using coke, the superior quality of the castings obtained more than justifies the extra fuel cost. In melting iron, about 700 cubic feet of artificial gas of a calorific value of 600 B. t. u.'s was required for each hundredweight of metal melted. The English hundredweight of 112 pounds is here indicated. From each crucible from seven to nine heats of iron were obtained.

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